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VOLUME 8 JANUARY, 1933 NUMBER 1

MEASUREMENTS OF IONIZATION IN THE KENNELLY-HEAVISIDE LAYER DURING THE SOLAR ECLIPSE OF 1932[1]

BY JOHN T. HENDERSON[2]

Abstract

The ionization of the Kenelly-Heaviside layer was measured by Appleton's method during the total solar eclipse of August 31, 1932. In contrast to normal days, a sudden decrease of 58% during the period of optical totality was found. This is shown to be in accord with Appleton's, but not with Chapman's, theory that the cause of lower layer ionization is ultra-violet light from the sun. Some measurements were made of the effective height of the Appleton layer and these are discussed in detail. There is a marked effect at the time of optical totality on this layer also.

Introduction

In the early days of radiotelegraphy great difficulty was experienced in explaining how electromagnetic waves travel so far round the earth. At about the same time Kennelly in the United States, and Heaviside in England suggested that there might be an electrically conducting layer in the atmosphere which reflected, or bent, the radio waves down towards the earth. It was not until 1925 that Appleton and Barnett (4) proved the existence of such a layer by direct experiment, and in 1926 the point was confirmed by Breit and Tuve (7) using a different method. About a year later Appleton demonstrated (2, 3)* that there were in reality two such regions, the lower one called the Kennelly-Heaviside layer, or E region, being some 100 km. above the earth's surface, and the upper one, the Appleton layer, or F region, being about 250 km. high.

The cause of the existence of these layers was naturally the subject of speculation, and the special advantages of investigating the electrical state of the upper atmosphere by radio methods during a total solar eclipse have been emphasized recently by Appleton (6) and by Chapman (8). They have pointed out that such observations would discriminate between the rival theories concerning the origin of ionization in the lower conducting layer.

[1] *Manuscript received November 22, 1932.*
Contribution from the Macdonald Physical Laboratory, McGill University, Montreal, Canada.

[2] *Holder of a Province of Quebec bursary.*

* *See also Reference (12).*

Advantage was therefore taken of the total solar eclipse of August 31, 1932 by many investigators, to test some of the points at issue. The results obtained by the Canadian expeditions are described in this and the accompanying papers (9, 11).

During the total eclipse of 1927, Appleton made observations in which the relative signal strength of the downcoming wave was compared with the strength of the ground wave, and the ratio was found to increase at the time of totality. The height of the Kennelly-Heaviside layer, measured by the frequency change method, was also found to increase at the time of the eclipse. The observations have since been interpreted by Appleton as being strong evidence in favor of the hypothesis that ultra-violet light from the sun was a principal agent in the production of ions in the lower layer. Professor Chapman, however, was inclined to attribute the cause of ionization to neutral particles shot out from the sun by radiation pressure. The difference to be expected in the effect of an eclipse, if the cause of lower layer ionization be particles on the one hand, or ultra-violet light on the other, has been discussed by Chapman (8),* and by Appleton and Chapman (5).

The map reproduced on page 35 gives the positions of the central line of the umbral shadow on the ground, both at a height of 100 km. and at a height of 200 km. It also shows the southern limit of the expected corpuscular, or particle, eclipse. The "shadow" extends eastward as far as Europe, the central line running through Greenland and the Atlantic Ocean. This "corpuscular" shadow is displaced from the optical shadow in place and in time. If therefore the ultra-violet theory is correct the maximum reduction of ionization due to the removal of the producing agent should take place about the time of optical totality, and the best position for observing it would be under the shadow on the lower layer. If the corpuscular theory is correct, then the maximum reduction in ionization should take place some two hours earlier and the best position for observing it would be over the Atlantic Ocean.

To satisfy these conditions as nearly as possible, one party was located at Vankleek Hill, Ontario, directly below the shadow at 100 km., and one party at Corner Brook, Newfoundland, about 300 km. east of the predicted western boundary of the corpuscular eclipse.

The method adopted in the present investigation was that, developed by Professor Appleton (6), of directly measuring the ionic content of the layer, the object being to follow the changes in ionic density in the lower layer throughout the eclipse period.

Experimental Details

The procedure was to use the well-known impulse method of Breit and Tuve (7). Very short signals are sent out from a transmitting station and reach the receiver by two distinct paths, one ray travelling along the surface of the ground, and one travelling up to the reflecting region and back to the

* *See also Reference (10).*

receiver. The retardation of the second signal behind the first, or direct wave, is a measure of the equivalent height to which the indirect, or sky wave, has travelled. The experiment is further simplified by placing the sending and receiving stations as close together as is convenient (*e.g.*, 2.7 km. at Vankleek Hill), so that reflection takes place at normal incidence.

At the receiving station, the signal, after suitable amplification, is rectified and impressed on a cathode ray oscillograph. Visual observation and photographic recording are maintained simultaneously.

To measure the ionic content, the frequency of the transmitter is increased step by step. At first the reflected wave or echo is found to come from the lower layer (Kennelly-Heaviside, or E, region). As the frequency increases, for all frequencies greater than a certain critical value the echo no longer returns from region E but comes from the upper, or F, region (Appleton layer). This critical penetration frequency gives a count of the maximum number of ionic carriers present in the layer. The relation here used to calculate the ionic density is $f^2 = kN$, where f is the penetration frequency observed, $k = 0.184 \times 10^{-7}$, and N is the number of electrons per cubic centimetre in the Heaviside layer. The assumptions involved and the limitations of the above formula are discussed by Appleton and Naismith (6).

Apparatus

Transmitting Stations

The transmitter used is a simple tuned-plate tuned-grid circuit. To emit the short signals necessary the transmitter is keyed in the common negative lead by a mechanical commutator driven by a synchronous motor. The length of the impulses, using this form of keying, varied from 0.3 to 0.5 millisec. (measured on the receiver oscillograph). Although longer than desired, they are not so long as to inhibit accurate measurement of the critical penetration frequency. The recurrence frequency of the impulses is 30 per sec.

The aerial is fed directly through a tap on the anode coil. At Vankleek Hill the aerial system is a simple inverted L, mounted on masts 60 ft. high, with a horizontal top about 250 ft. long. The dimensions of the Corner Brook aerial are only slightly smaller.

The experiment is, of course, controlled from the receiving end which is in telephonic communication with the sending station. The wave-length is, however, measured at the transmitter, a General Radio precision wavemeter being used as a reference.

Receiving Stations

The receiver for Vankleek Hill was constructed at the Radio Research Station, Slough, and follows the current English design of receivers for this type of work. It is a superheterodyne set with one tuned stage of signal frequency amplification. The output of the local oscillator can be adjusted

for optimum heterodyne. The I.F. amplifier has a gain of 90 db. and a flat band pass of 15 Kc. (kilocycles per sec.) centered on 112½ Kc., the cut-off being fairly sharp on both sides of the band.

The output to the oscillograph is taken directly from the second detector to the plates of the oscillograph, audio-frequency amplification being unnecessary and not very desirable. By using a diode rectifier the first 0–20 volts output is made linear with input. From 20 to the maximum output of 65 volts this linearity is departed from, but that is not important, since the point of making the over-all characteristic linear is to ensure that the small echoes (*i.e.*, weak signals) show on the oscillograph screen.

The Corner Brook receiver was a recent commercial model. The only alteration made was to cut out an audio-frequency stage fed through transformers, as this form of coupling is not suitable for echo work. One resistance-coupled audio-frequency stage was left in, the output of the oscillograph being taken across a resistance of 5000 ohms.

A linear time base is supplied, and to calibrate it the note from a 1000-cycle hummer (General Radio) is put on the oscillograph (replacing the echo pattern) after each change of transmitter wave-length and photographed. The time spread used varied throughout the experiment according to the number of multiple echoes it was desired to photograph, but a common spread is 1.5 cm. per millisecond, so that time intervals can be measured fairly accurately.

Much of the preparatory work was done in England at the Radio Research Station, and at King's College. The apparatus was then installed in McGill University, Montreal, for preliminary tests and observations. The heights of the ionized layers were first measured on July 19. The equipment was later moved to Vankleek Hill and Corner Brook, the experiments proper being done between August 28 and September 3, inclusive. The time of observation was from 1500 to 2400 G.M.T.*

Results

A. *Vankleek Hill, Ontario*

Every half-hour photographs were taken on the three fixed frequencies, 4.0, 3.16, 2.73, Mc.† (75, 95, 110 m.). The first of these values was chosen to give upper layer reflection always, the second is the critical penetration frequency for 1830 G.M.T., and the third is the critical penetration frequency for 2030 G.M.T., both for normal days. The remainder of each half-hour was devoted to determining the penetration frequency for that particular period, which was found as often as possible. Generally speaking the accuracy of the determination is good (usually about 2 or 3% and sometimes as high as ½ of 1%), but when echoes from both layers are found over a wide band of frequencies, or when the echoes become very small, and sometimes disappear entirely over a small range of frequencies close to the critical one, then the accuracy is naturally diminished in proportion.

* *In this notation 1918 G.M.T., for example, means 19 hr. 18 min. Greenwich Mean Time.*
† *Mc. means megacycles per sec.*

One further difficulty was encountered on August 28, 29 and 30. For each of these days there appears one blank interval during which it was impossible to get echoes on any wave-length at our command (*viz.*, 45–170 m.). These periods are:

August 28.....1610 to 1918 G.M.T. (3 hr. 8 min.)

August 29.....1950 to 2210 G.M.T. (2 hr. 20 min.)

August 30.....2118 to 2310 G.M.T. (1 hr. 52 min.)

which decrease in length and appear later in the day. No such blank periods were noticed after August 30; nor were they noticed on the previous week during the preliminary tests.

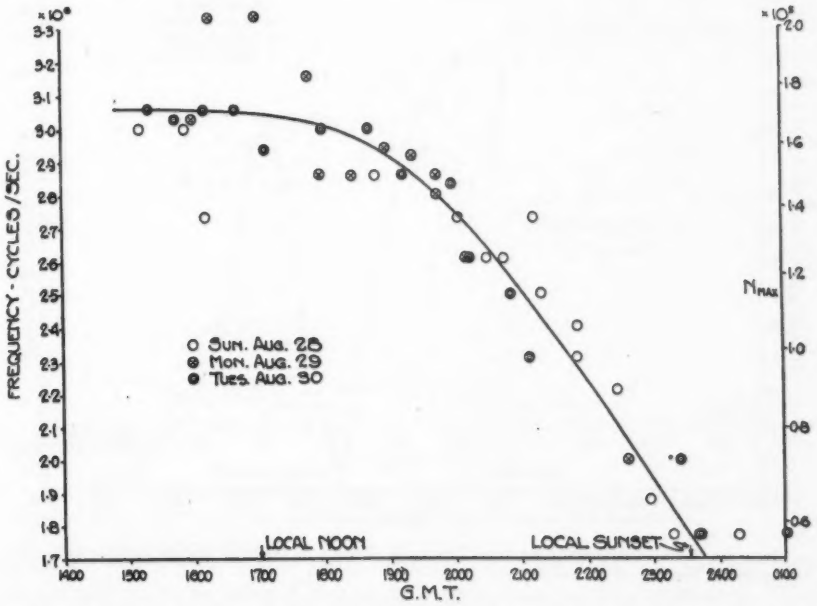


FIG. 1. *Critical frequency on the left and ion density on the right plotted against time, for the three successive days preceding the eclipse.*

On September 1, the recording was interrupted from 1618 to 2302 G.M.T. by a local thunderstorm of considerable violence. Despite these blank intervals it is felt that the curve presented in Fig. 1, showing the variation of ionic density in the Heaviside layer throughout the day, is a good approximation to the actual conditions existing on a normal day at this time of year. The points are shown for August 28, 29, 30, only, but those for September 2 and 3 fit equally well on this same curve, and have been omitted only to avoid confusion.

In Fig. 2 is shown the same curve for August 31, 1932. In this graph the inked-in circles represent frequencies showing lower layer reflection. The open circles are frequencies reflected from the upper layer. A circle half black denotes either the actual critical frequency, or a frequency showing reflection from both regions. (When it is not possible to give the exact value, the critical frequency will obviously lie between a point which shows reflection from the lower layer and one which shows reflection from the upper layer.) There is no doubt about the coincidence of the removal of the ionizing agent with the shutting off of the sun's light by the moon. The

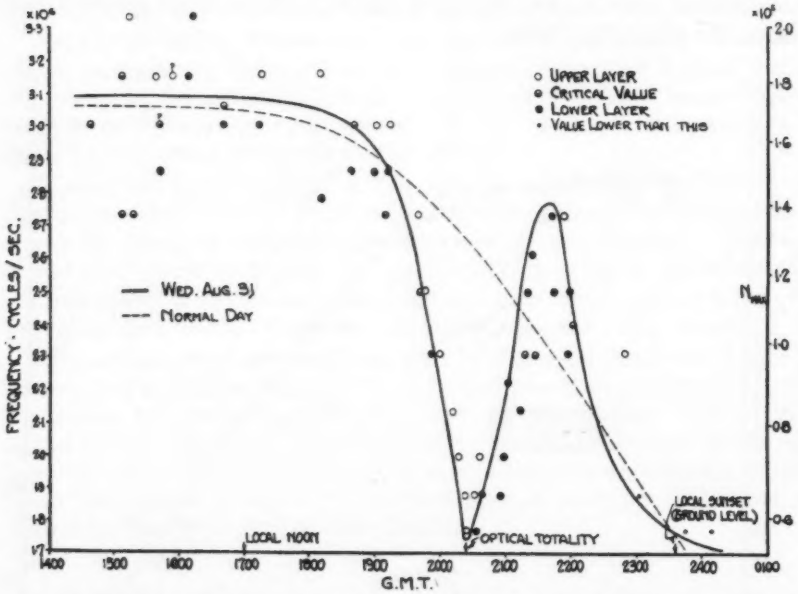


FIG. 2. *Critical frequency on the left and ion density on the right plotted against time, for August 31, the day of the eclipse.*

difficulty was not in noticing the effect, but in following the rapidly changing critical frequency. The penetration of the lower layer by a frequency of 1.72 Mc. (170 m.) at a time of day when 2.72 Mc. (110 m.) is only just going through, and the subsequent reflection of this abnormally low frequency by the re-forming E region ten minutes after totality is, in itself, sufficiently striking. No abnormal behavior was noticed on August 31 before about 1915 G.M.T., and certainly conditions in the layer were normal at 1830 G.M.T.

It will be noted that, after the eclipse, the ionization increases between 2100 and 2200 G.M.T. to a value higher than normal. The duration of the electrical effect is about two hours, judging solely by the width of the sudden depression in the ionization curve. The maximum effect (*i.e.*, minimum ionization) coincides with totality to within three minutes.

Fig. 3 gives the variation of the equivalent height throughout the day for 2.73 Mc. Normally this frequency is returned from the lower layer until about 2030 G.M.T., when it penetrates and is then returned from the upper layer. This condition is illustrated in the dot and dash curve, which is the curve for the other six days of the experiment, and is considered to represent normal conditions at this season. Actually the normal time of penetration is best represented by an area, as this time varies slightly.

On the day of the eclipse, conditions were much as usual until about 1930 G.M.T. when penetration occurred about an hour earlier. The height of the upper layer instead of remaining roughly constant showed a sudden increase shortly after totality, with a return to more normal heights immediately afterward. There was another slight increase in height about 2240

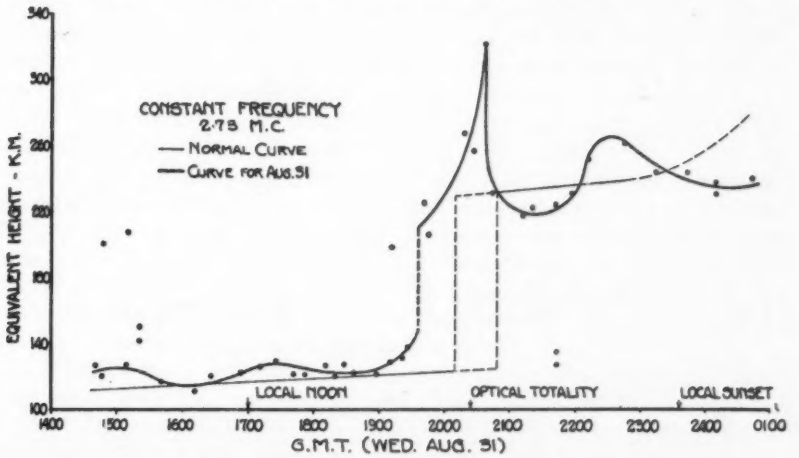


FIG. 3. *Equivalent height of reflecting layer for 2.73 Mc. constant frequency, plotted against time. Contrast between normal curve and curve for August 31 indicated.*

G.M.T., just a little before ground sunset (*i.e.*, 2336 G.M.T.), but as this is sometimes found on other days also, it is not considered very abnormal. The point at 2026 G.M.T. was observed for four minutes, and the height is based on 22 pictures taken at this time.

The isolated points at 2145 G.M.T. are interesting. In the first place they show that the ionization in the lower layer was strong enough to return part of the energy on this frequency, thereby indicating an abnormally high ionic content in region E. Secondly, four echoes show on 8 of the 12 photographs taken at this time, but the measured heights vary considerably in the different pictures so that we are undoubtedly dealing with a temporary and unstable state. The greatest part of the reflected energy is in the F'_1 echo*, whose

* *The echoes are named for the region from which they are returned. Thus* E_1, E_2, E_3 . . . . *are echoes from the* E *region, the suffixes denoting whether they are the first, second, or third reflections. Primed letters, e.g.* F'_n, F''_n, *denote the components of the* n^{th} *reflection of an echo showing magneto-ionic splitting.*

height is constant. The E_1 echo shows only spasmodically; F_2 shows occasionally. The photographs are reproduced in Plate IV and are discussed more fully below. The equivalent heights plotted in Figs. 3 and 4 are calculated from the time delays to the first sign of an echo, except where echoes from both layers are present as in this instance, and again between 1400 and 1500 G.M.T.

The split components are not shown separately, because the rather long impulse used does not permit our separating them with any pretence at accuracy. Multiple echoes are not marked on the curves, as the energy will be returned from the regions shown since multiple echoes are interpreted as being due to multiple reflections from the same height.

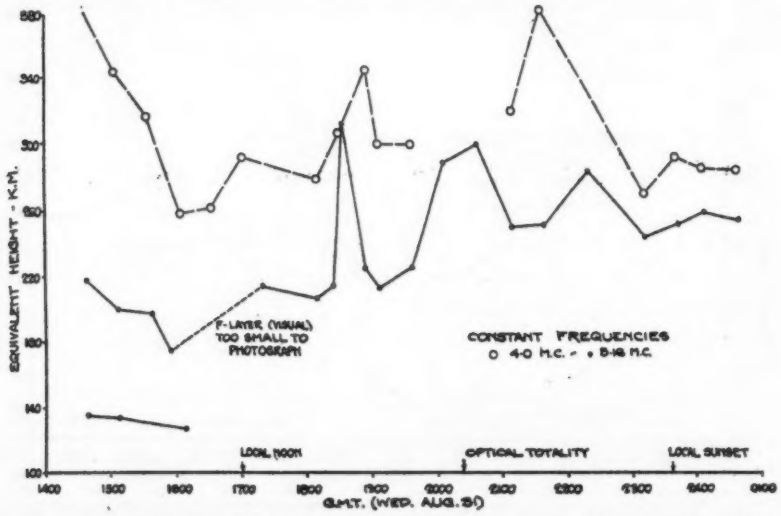


FIG. 4. *Equivalent height of reflecting layer for 4.0 and 3.16 Mc. respectively, plotted against time.*

The lower curve in Fig. 4 is for 3.16 Mc. Ordinarily this frequency is just on the border line and may show lower layer echoes for a few hours about midday when region E is most intensely ionized. Unfortunately the frequency is slightly high and on several days the maximum noon ionization was not sufficiently great to reflect this frequency. All the control days of the experiment show upper layer reflections after about 1830 G.M.T., and a gradual increase of height with time until about 2200 or 2300 G.M.T., when there is a slight fall.

On August 31 this frequency gives only occasional lower layer echoes in the early forenoon and upper layer from 1630 G.M.T. onwards. There seems to be a sudden increase of height at 1830 G.M.T., lasting only a short time and based on four pictures taken in three-minute observations. There is a more marked increase between 2000 and 2100 G.M.T., and a minor increase at 2230 G.M.T.

The broken line represents layer heights for 4.0 Mc. and has roughly the same general shape as that for 3.16 Mc. Unfortunately the most interesting part of the curve is missing, because about totality the noise and interference from other stations increased so much that photographic and visual observations were impossible. Judging from reception of outside stations night-time conditions were restored about totality.

It is well known that conditions in the ionized layers are extremely variable. For 4.0 Mc. this statement is only too true, and the "normal" conditions are very difficult to determine from the erratic curves obtained on the six control days. All that can be fairly said is that there is no sudden appearance of night-time reception conditions.

Of the three equivalent height curves shown, that for 2.73 Mc. has the most weight, and that for 4.0 Mc. the least, Fig. 4 being presented chiefly for comparison with Fig. 3. Of course the character of the photographs is a considerable aid in drawing the curve. Thus the point on the 2.73 Mc. curve at 2036 G.M.T. is not dismissed lightly as a single observation, because it is based on a little longer period of observation than the others and on a greater number of pictures. Conditions on all three frequencies about totality resemble night-time conditions more closely than at any other time of the day (*viz.*, larger echoes, multiples more frequent, and more noise and general interference). Although none of the reproductions show good examples of multiple splitting, these are frequently observed in the evening and at night, three echoes from the upper layer being quite common. In the daytime the general rule is one or two echoes, with the second often quite small, so that the appearance of three large echoes at totality, with signs of a fourth, on 2.73 Mc. (110 m.), was quite a spectacular result.

In Plates I to V are shown some samples of the photographic evidence from which the above curves are drawn. The photographs are a long series of individual exposures and, for purposes of reproduction, have been rephotographed on a reduced scale, the original records being 10 cm. wide. Plates I to III show three columns to be read downwards in succession (starting with the left-hand one). Plate V may be regarded as the magnified reproduction of an omitted third column in Plate IV. *The temporal sequence of events is from right to left in all cases.* The small figures under the row give the time of the observation (G.M.T.) and the wave-length in metres. With the exception of Plate V all photographs were taken on August 31.

Thus the first column (Plate I) shows three pictures of upper layer echoes on 75 m. The ground wave (the first signal) is considerably larger than the echo. The equivalent height in this case is 343 km. The time interval between successive photographs is small, and throughout the whole of the records it is often observed that the echo varies rapidly in character and amplitude. Below these three pictures are two photographs of the 1000-cycle calibration frequency. The wave form is distorted and the pattern superimposed twice on the screen, so that the distance between *alternate* peaks is one millisecond. The return stroke of the time base also shows, but has no significance here.

In column 2 are shown lower layer echoes on 2.73 Mc. (110 m.). Some noise is apparent on this frequency, but the photographs illustrate the ease with which the echo pattern can be seen through the interference, this being one of the chief advantages of the method. At 1625 G.M.T., 2.73 Mc. was reflected from the Kennelly-Heaviside layer, but between 1926 and 1940 G.M.T. this frequency had penetrated the lower layer, and at the top of column 3 will be seen the upper layer echoes taken at 1940 G.M.T.

Below this are four photographs on 2.50 Mc. (120 m.). The equivalent height is about 140 km.. The pictures show the complicated splitting that usually occurs just about the critical frequency. Five minutes later this frequency had penetrated the lower layer and was being returned from an effective height of 225 km.

Plate II, column 1, shows a large increase in the magnitude of the F layer echoes on 3.16 Mc. (95 m.) 17 min. before totality, and this presumably indicates decreased absorption in the E region. The F layer echoes on 110 m., column 2, (taken at 2008 G.M.T.) were approaching normal night-time magnitude and complexity. Small second reflections can be seen on three pictures, and the rapidly changing shape of echo is marked. In the third column is shown the penetration of the lower layer by 1.88 Mc. (160 m.) one minute before the eclipse. The noise was then much worse than normal.

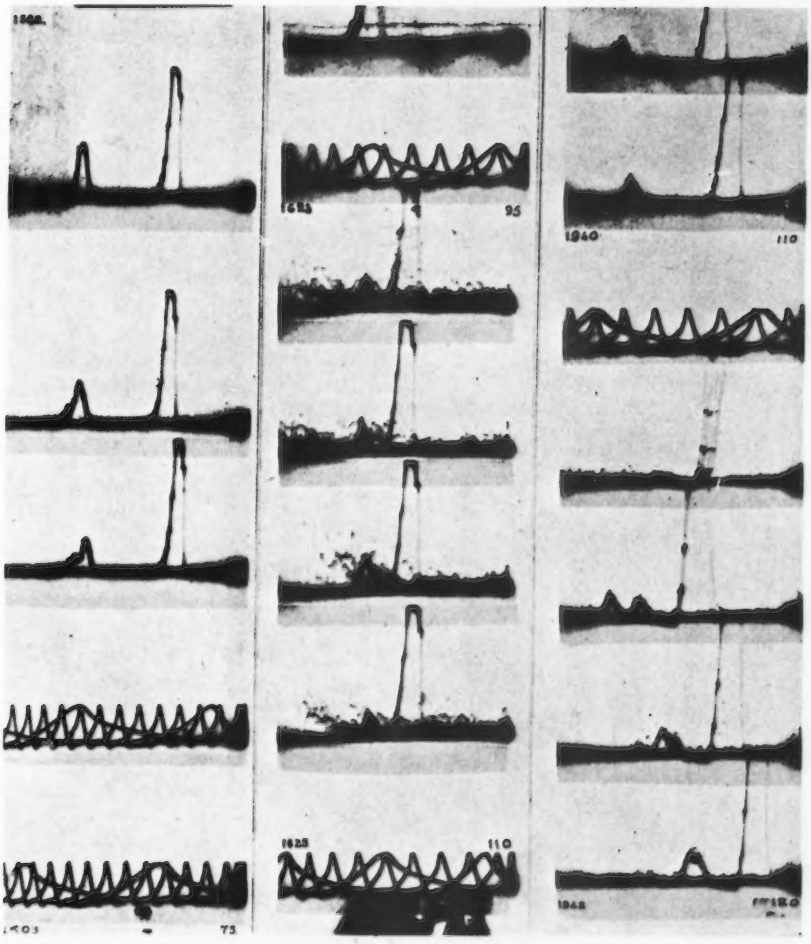
Plate III shows the penetration of the E layer at 2025 G.M.T. (one minute after totality) by 1.77 Mc. (170 m.) the height being 222 km. Ten minutes after the eclipse this wave-length is again being reflected from the E region (see bottom of second column).

In the previous plate it was seen that 160 m. was penetrating the E region at 2023 G.M.T. At 2031 G.M.T. the height was 188 km.; at 2040 G.M.T. it was 145 km., and by 2058 G.M.T. this wave-length was being returned from 122 km., which is a normal value of the height of the Heaviside layer (see columns 2 and 3).

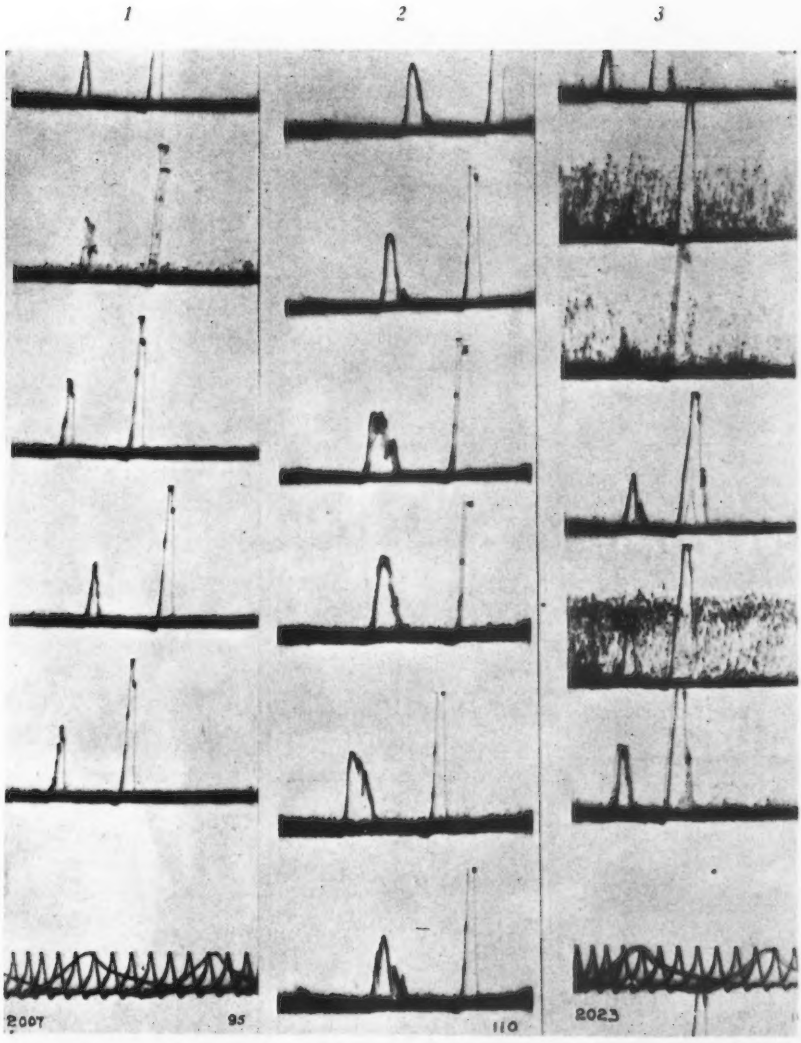
The behavior observed on the frequencies 1.77 and 1.88 Mc. is positive evidence of the abnormally low ionic content in region E.

Plate IV shows the complex echoes on August 31 at 2146 G.M.T. on 2.73 Mc. (110 m.). It will be observed that the F_1 echo is always present and by far the largest. It is the echo whose time delay corresponds to the height shown on the curve in Fig. 3. The E echo is present only on some of the pictures, so this frequency presumably gives the peak of the increasing lower layer ionization curve, after the eclipse. In row 2 of column 1, the various components are labelled. The calibration frequency for timing the echoes in column 1 is at the top of column 2. After this the time spread was changed and the last row in column 2 gives the calibration frequency for the remaining five photographs, 12 in all being taken on this frequency at the time in question.

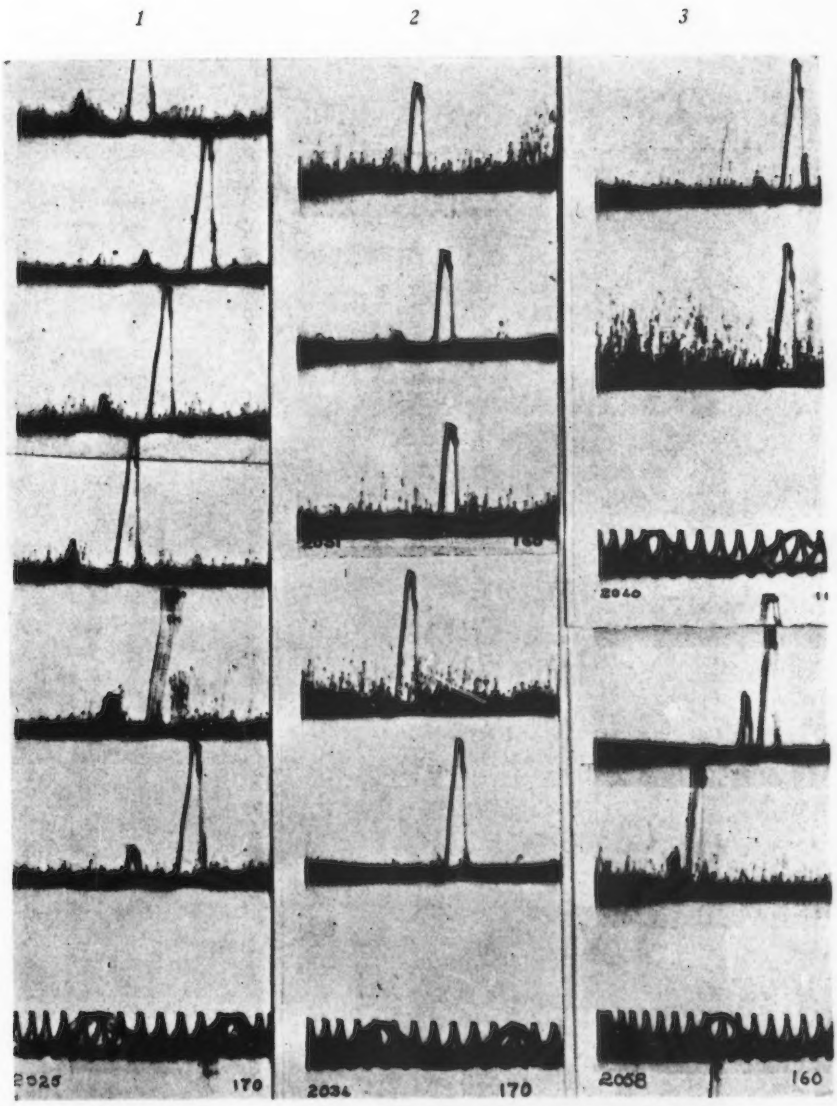
Plate V is the only set of reproductions not taken on August 31. It is on 4.0 Mc. (75 m.) at 1630 G.M.T., on September 2, and shows a good example of simultaneous reflection from both layers. Incidentally this is rather a high frequency to show a lower layer echo.



Echo patterns showing reflection from lower layer and eventual penetration to upper layer, also 1000-cycle time scale calibration. (Read patterns from right to left. Ground wave is large pulse at the right in each case).

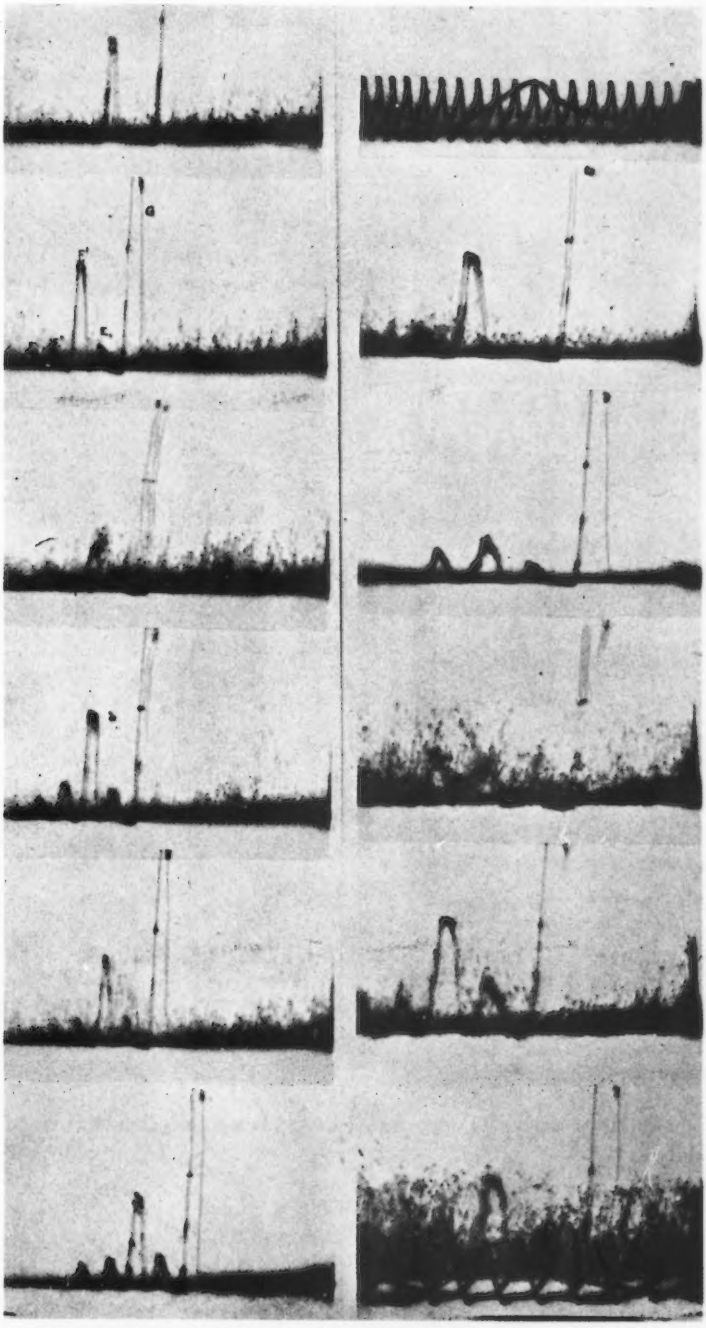


Echo patterns on 3.16 and 1.88 Mc. just before totality. (Note the noise appearing in column 3, confirming approach of night-time conditions).

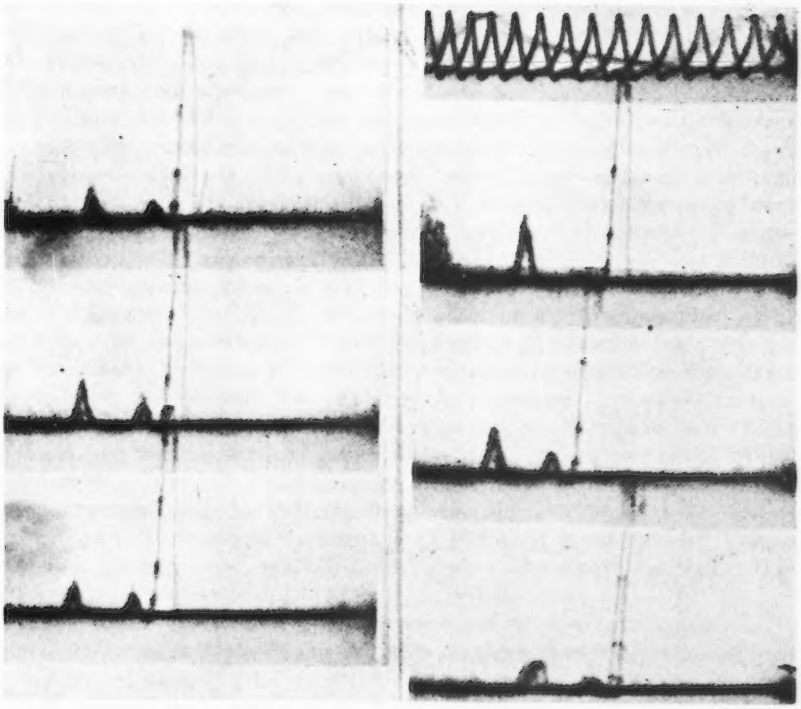


Echo patterns on 1.77 and 1.88 Mc. at and following moment of totality. (Note change from upper layer to lower layer reflection at bottom of column 2, 10 minutes after totality).

1 2



Echo patterns showing complex splitting of reflections on 2.73 Mc. following totality. (Components are labelled in second row of column 1).



Echo patterns showing simultaneous reflections from both layers on 4.0 Mc. (Taken on Sept. 2, at 1630 G.M.T.).

B. *Corner Brook, Newfoundland*

Here the evidence presented, although of a less convincing nature, can be used in support of the main conclusions to be drawn from the Vankleek Hill observations. The expedition was hampered by lack of time and a location very difficult to work in, owing to the extremely high electrical noise level encountered and the rather unsuitable terrain. The choice of observing site was governed by the question of power supply, this forcing a selection which otherwise might have been improved.

Observations were consequently delayed until August 31, but continued until September 3. Lower layer echoes were observed on two occasions only, so that the existence of lower layer echoes was inferred from the disappearance of upper layer echoes as the frequency of the transmitter was reduced. The method is somewhat analogous to the determination of the critical penetration frequency of the Appleton layer where this is determined by noting the maximum frequency for which upper layer echoes can be obtained, but the inversion of the process is less legitimate here. Only relatively large echoes give any indication of their presence, so for the most part even upper layer echoes are lacking. The upper layer echoes, however, do show through at night fairly regularly in consequence of the decreased absorption in the lower layer permitting a greater return of energy, so that on the day of the eclipse a return to night-time conditions would be inferred if these echoes are obtained.

The experimental procedure was similar to that at Vankleek Hill. The fixed frequencies 2.7 and 3.2 Mc. were observed and photographed every half-hour. A rough attempt to find the critical penetration frequency for the lower layer, by noting the minimum frequency on which the upper layer echoes could be obtained, was made in the remaining portion of the half-hour. The critical frequency obtained in this way would tend to be too high, because often the magnitude of the upper layer echoes decreases as the critical frequency is approached. Unfortunately, intercommunication troubles between the stations rendered this determination very difficult.

On August 31, no echoes were seen until 2030 G.M.T. on 3.3 Mc. Echoes were first photographed at 2100 G.M.T. when the equivalent height was 250 km. for a frequency of 2.7 Mc.

On September 1, 2, and 3, echoes were not obtained until 2300, 2130, 2130 G.M.T. respectively (being first seen on the higher frequency and then on the lower, as would be expected). Local time is 2½ hr. earlier than G.M.T. and ground sunset was at 1846 G.M.T.

We would interpret these results as indicating that night-time conditions set in at least one hour earlier than usual on August 31. That echoes were not seen about 1830 G.M.T. is taken as evidence that there was no corpuscular eclipse, but it must be borne in mind that we are at all times arguing from incomplete data when discussing the Corner Brook results.

Discussion

It is not difficult to deduce the main conclusion from the results under consideration. For the Kennelly-Heaviside layer we can say with certainty

that the ionization in the path of the shadow decreased by at least 58% during optical totality. There was no indication of abnormal conditions about 1830 G.M.T., so that we conclude there was no particle eclipse in the shadow belt. The results from Corner Brook support these statements. In Newfoundland either there was no particle eclipse, or its effect was much smaller than that of the partial optical eclipse, the latter apparently being accompanied by a decrease in lower layer ionization.

The experiment is regarded as giving substantial proof of Appleton's theory that the predominant cause of lower layer ionization is the sun's ultra-violet light.

Ample corroboration of this statement is to be found in the work of other investigators during the recent eclipse, part of which has been summarized already from preliminary reports and appears in "Nature", September 10, p. 385 (1932). For example, trans-Atlantic signals from Rocky Point, N.Y., were received at Cupar, Baldock, and Dollis Hill in Great Britain. The frequency was 60 Kc., so that the lower layer is almost certainly the region involved. Although no important changes were noticed on the day of the eclipse at the two latter stations, Cupar receiving station gave a curve of signal strength variations which shows an abrupt decrease in strength between 2015 and 2018 G.M.T. followed by an increase which exceeds the normal value at 2030 G.M.T. The curve has added interest in that it shows no effect that could be ascribed to particles despite the fact that the transmission for the most part takes place inside the region of the predicted corpuscular eclipse. The exceptional increase in signal strength after the eclipse should be compared with the increase in ionization observed in Ontario shortly after totality.

This abnormal increase of ionization after the eclipse may be due, in part, to a local thunderstorm which occurred near Ottawa soon after totality. Professor Appleton finds that an increase of ionization actually does occur during thunderstorms as one would expect from C. T. R. Wilson's theory, and suggests it as a possible explanation here.

From the preliminary report it appears that the Bureau of Standards in Washington also measured ionic content of the lower layer and obtained results in close agreement with those described herewith, indicating "that the partial ultra-violet eclipse at Washington with a duration of about 1½ hr. was accompanied by a slightly lagging reduction of something between 35 and 60% in the density of ionization in the Kennelly-Heaviside region".

The main results of other Canadian experiments described in the third paper of this series (9) are also in agreement with the conclusion just drawn, and we have no hesitation in ascribing the predominant cause of lower layer ionization to ultra-violet light from the sun.

For the upper layer our own results are not as decisive as those for the lower layer, which latter region indeed was our primary consideration. From the variation of equivalent height of the upper layer on two or three frequencies we would say that there was a reduction in the ionic content of the

Appleton layer about totality, with a subsequent increase to more normal values after the eclipse. Thus far the statements are definite and based on fairly reliable data.

More indefinite are some vague suggestions of an increase of effective height about 1830 G.M.T. Whether this is merely some chance variation, or whether it is a real "particle" eclipse, we are not prepared to say from these results only. The brief sketch of the results obtained at Cambridge, England, seems to bear out these remarks concerning a small particle eclipse, but the vagaries of the ionized layers are well known and more conclusive information is desirable. Furthermore, our own station in Ontario was situated beyond the western boundary of the predicted particle eclipse, and for the English station the particle eclipse ended about sunset so neither station was in a suitable location for observing the effect. Corner Brook, in a better situation than Vankleek Hill, reports that on 50 m. communication conditions underwent some modification, outside stations being heard more strongly than usual, or were heard when normally inaudible, but the evidence is not altogether conclusive. We must return the verdict of "not proven" on the point, when speaking of our own observations.

The equivalent height curve for 4.0 Mc. is a particularly bad one from which to draw inferences of ionic content, because the observed height varies most erratically on the other six days of observation; in fact the upper curve of Fig. 4 is no worse than for the other days. The curve for 3.16 Mc. is a little better and that for 2.73 Mc. is good, but on the debatable point of an effect at 1830 G.M.T. this last curve is useless since the signals are then reflected from the Kennelly-Heaviside layer.

Definitely it can be said that night-time conditions were much more closely approached during optical totality than at any other time of the day, which would indicate that the chief cause of ionization in the Appleton layer, as in the Kennelly-Heaviside layer, is ultra-violet light from the sun.

In presenting the results it was mentioned that on each one of the days August 28, 29 and 30, a blank period occurred during which it was impossible to obtain echoes on any frequency between 6.0 Mc. and 1.77 Mc. It is known that these days were magnetically disturbed days. Appleton and Naismith (6) have shown that, under such conditions, the ionization in the E region is more intense than usual. It seems extremely unlikely that, during the blank periods we speak of, the ionization of both layers should temporarily decrease to such an extent that even 1.77 Mc. penetrated the upper layer. Such an hypothesis would necessitate an enormous decrease in upper layer ionization. It is possible, however, that the "D" layer, noticed by Appleton (3), which is an ionized region below the E, normally capable of absorption but not of reflection of radio waves, was unusually intensely ionized, and the sky wave was so heavily absorbed on all our available frequencies that no reflections were obtained. The suggestion is put forward very tentatively as there is no decisive evidence to support it.

We conclude that the importance of ultra-violet light as the primary cause of ionization in the lower layer is established. Ultra-violet light is also

an important cause of upper layer ionization but its relative importance in this case cannot be deduced from the present experiments. There was no particle eclipse for the lower layer in Ontario.

Acknowledgments

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Gratitude is specially due to Mrs. J. A. Henderson for accommodation in her house for the receiving station during tests. (A.S.E.)

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RADIO OBSERVATIONS ON THE UPPER IONIZED LAYER OF THE ATMOSPHERE AT THE TIME OF THE TOTAL SOLAR ECLIPSE OF AUGUST 31, 1932[1]

By D. C. Rose[2]

Abstract

This report contains the results from one of the three stations set up by the National Research Council of Canada to take observations on radio reflections from the ionized layers in the upper atmosphere during the total solar eclipse of August 31, 1932. The station concerned was located at Kingston, Ontario, and was approximately under the centre of totality for the upper, or Appleton layer. Hence observations at this station were limited to the upper layer. The results from the other two stations at Corner Brook, Newfoundland, and at Vankleek Hill, Ontario, are reported in the paper immediately preceding (8).

The method was that developed by Breit and Tuve, in which a short pulse is transmitted, the reflection being received and its time delay recorded by means of a cathode ray oscillograph.

The results indicate that the ionization of the upper layer is caused by radiation (presumably ultra-violet light) from the sun. Whether or not this is the sole cause is uncertain because of the time lag in recombination of ions in the layer. A reduction in ionization of over 30% was noted.

A magnetic storm which occurred a few days before the eclipse made the results more difficult to interpret but gave some information of the effect of such a storm on the upper layer. It appeared to cause considerable instability in the layer and a somewhat lower ion content.

Introduction

In this paper the results of observations taken at Kingston, Ontario, on reflections of radio waves from the upper ionized layer of the atmosphere are given and discussed. The paper by Henderson (8) describes the results of observations taken at the time of the eclipse at Corner Brook, Newfoundland, and at Vankleek Hill, Ontario. The object of these experiments was to decide definitely whether or not the ionization in the reflecting layers, particularly the lower layer, was caused by radiation from the sun, such as ultra-violet light, or by corpuscles shot out from the sun. The two theories were introduced by Appleton and Chapman, respectively. The nature of the problem is well described in the early paragraphs of Henderson's paper and by Chapman (6) and by Miller (10), so little need be said about it here, except that a total eclipse of the sun offers an excellent opportunity to distinguish between the two possible phenomena. Although Chapman's theory suggests that only the lower, or Kennelly-Heaviside, layer is likely to be caused by particles, a knowledge of the behavior of the upper or Appleton layer under the conditions of a total solar eclipse, where solar sources of ionization are cut off relatively rapidly for only a short period, is also of great interest. Also the behavior of the reflecting layers in general had not hitherto been investigated in Canada. Hence an investigation of the upper layer in co-operation with the two stations mentioned above was necessary

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Contribution from the National Research Laboratories, Ottawa, Canada.

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in order to obtain as complete a knowledge as possible of reflections of radio waves over the period during which observations are being reported.

Kingston was chosen as a site for observations on the upper layer because it was just under the central band of totality for a height of about 220 km. The results indicate that a location 50 to 70 miles farther west would have been nearer the desired location (under the central line of totality for the upper layer), as the layer at the time of the eclipse was found to be between 300 and 400 km. in height. However, such a location farther west should have a negligible effect on the results, because the shadow band was of the order of 100 miles wide and the effects of the eclipse on radio reception should not be very different for totality and for conditions a few per cent under totality.

Apparatus and Procedure

Transmitter

The method of measurement was that developed by Breit and Tuve (5). In this method the time lag is measured between the reception of a short signal coming directly along the ground, and the reception of the same signal reflected from the ionized layer in the upper atmosphere. The transmitting apparatus consisted of a short-wave transmitter developed by the Royal Canadian Signals and designated as their *M*6 transmitter. It consists of a Hartley circuit using two *UX*852 oscillator valves in parallel. It had an output of about 200 watts and was arranged to work at wave-lengths between 15 and 90 m. It was conveniently mounted for transportation and was self-contained in that it included its own rectifier power unit fed from 110-volt lighting lines. The keying operation was performed by interrupting the negative power lead.

For the present experiment a short signal of the order of one four-thousandth of a second was sent out 30 times per sec. The received signals appear to be of greater duration than one four-thousandth of a second probably because of the time required for oscillations to die down in the transmitter, or because the action of the receiver was too sluggish. The transmitter was controlled by a commutator which closed the key circuit for the required interval of time. The commutator was driven by a synchronous motor fed from the local 60-cycle power line. The wave-lengths were measured to an accuracy of better than 1% with a portable wavemeter loaned to us and calibrated by the Royal Canadian Signal Corps in Ottawa.

The transmitting aerial was that belonging to the Queen's University broadcasting station, the transmitter being set up in the radio laboratory of the Department of Electrical Engineering. The aerial appeared to work in a satisfactory manner at all wave-lengths used, though its natural period was in the broadcast band.

Receiving Equipment

The receiving equipment consisted of, first, a National *NC*5 five-tube short-wave converter which was designed to convert wave-lengths from 15 to

200 m. into the broadcast band at 575 Kc.* The converter was a superheterodyne type operated by alternating current. It was connected directly to a Stewart Warner T.R.F. eight-tube broadcast receiver, type *R*100. The audio-amplification in the broadcast receiver had to be altered to resistance-capacity coupling, as iron transformers would not respond properly to the short signal. However, after making the necessary alterations it was found that sufficient voltage to actuate the cathode ray oscillograph could be obtained directly from the detector. The output from the detector was connected through a potentiometer gain control directly to the vertical component plates of a von Ardenne cathode ray oscillograph.

The time axis or horizontal sweep of the cathode ray oscillograph was arranged by the usual method of charging a condenser through a high resistance until sufficient voltage is attained to break down a grid-controlled gas-filled valve (Western Electric Type 269*A*). The results would have been better if a linear time axis had been used by the introduction of a diode in the circuit, but owing to circumstances which made the time for preparation and testing of the equipment much too short it was impossible to arrange a linear sweep circuit in this case.

The receiving equipment was set up in the Physical Laboratory of the Royal Military College in Kingston, which is about a mile and a half from the transmitting station at Queen's University. The receiving aerial was hung between the roofs of the Physical and Engineering Laboratory buildings of the Royal Military College. It was from 20 to 30 ft. high and about 100 ft. long. The lead-in wire was connected from one end of the approximately horizontal section through a window to the receiving set.

Procedure

The apparatus was taken to Kingston on August 22 and set up as quickly as possible. This should not have taken long but owing to the fact that time had not been available to test all the equipment in Ottawa before moving it to Kingston some alterations had to be made, particularly in the time axis circuit on the cathode ray oscillograph. The circuit taken to Kingston and tried first was that recommended by Appleton and Builder (2), in which a condenser is discharged through a neon tube. In the present case a neon tube could not be found which always broke down at the same potential, so the arrangement had to be abandoned. The 269*A* valve gave much better results. The first oscillograms showing reflections were taken on August 23 using a 60-cycle wave as a time axis. The first run which gave satisfactory measurements of the frequency which penetrates the upper layer was obtained on August 26.

In the final arrangement of the time axis circuit, the circuit was coupled with the Ontario Hydro-electric 60-cycle power supply which was also feeding the synchronous motor, described above, used for keying the transmitter. This kept the time axis in synchronism with the incoming signal. This time

* *Kilocycles per sec.*

axis or horizontal sweep was calibrated periodically by changing the vertical sweep over from the receiver to the output of a General Radio beat frequency oscillator. This oscillator contains a vibrating reed by means of which one point on its scale can be calibrated. The rest of the scale was calibrated in Ottawa and found to be much more accurate than was needed. The frequency used for calibrating the time sweep was 1500 cycles per sec., so that one cycle corresponded to an equivalent layer height of 100 km.

The use of the time sweep circuit coupled with the a-c. power supply, as described above, made the a-c. power supply really the basis for time measurements, as the beat frequency oscillator had to be adjusted to make the approximately 1500-cycle wave (25 times the power frequency) stand still on the oscillograph screen. The inaccuracy in this process is the same as the inaccuracy in the frequency of the Hydro-electric power supply. However, on each occasion that the time axis was calibrated the frequency at which the beat frequency oscillator had to be set was noted, and it was found that for any observation the frequency of the power supply did not vary from 60 cycles per sec. by more than 1 or 2% and usually considerably less than 1%. The height measurements at their best involve possible errors greater than this amount.

It was intended that, after taking two or three days observations on the general behavior of the upper layer in the afternoon, two or three frequencies would be selected for height measurements. Observations would be taken on these frequencies, say, every 20 min. on the day of the eclipse and on the two days before and after the day of the eclipse. Between these 20-min. periods the frequency would be increased to find the minimum penetration frequency or the lowest frequency at which no reflection could be found. A private telephone line was established between the transmitting and receiving stations to facilitate frequency changes. However, due to a magnetic storm which started on August 27, and was particularly active on August 29 and 30, the plans were completely upset. The storm* had such an effect on the upper reflecting layer that it was impossible to select suitable frequencies for height measurements, or to find the penetrating frequencies representing an average undisturbed day, until after the eclipse.

Observations were taken on August 26, 27, 29, 30, 31 and on September 1 and 2. The runs were started about 1 p.m. E.D.S.T. (1700 G.M.T.**) and were continued until about 7 p.m. with slight variations in these times. On August 27 the results were rendered useless by a thunderstorm which was active for most of the afternoon. On Sunday, August 28, no records were taken, most of the day being spent in preparation for the rather strenuous continuous observations on the next five days. The activity of the magnetic storm mentioned above made it difficult to decide which of the seven days' observations should be taken as normal undisturbed days. The results of

** This storm also had a definite effect on the signal-strength measurements taken by the Canadian Marconi Company. (See the succeeding paper by Henderson and Rose (9).)*

*** 1700 G.M.T. means 17 hr. 0 min., Greenwich Mean Time.*

runs taken on August 26, September 1 and 2 show similar characteristics, hence these are taken to represent normal undisturbed conditions. In spite of some remaining activity of the magnetic storm on August 31 there is but little doubt of the effect of the eclipse on the ionization of the upper layer.

Considerable trouble was experienced due to interference from various sources. A thunderstorm in the neighborhood of course makes observations useless as mentioned above. However, fortunately only one day's results were spoiled in this way. Local power distribution lines in the neighborhood of the Royal Military College gave some trouble, but this was eliminated promptly by the radio inspector of the Department of Marine for Kingston. Another type of interference which gave a pattern of the type shown in example No. 10 of Plate I gave trouble intermittently on all days on which observations were taken. A test arranged with a Kingston citizen showed that the trouble was probably due to a high frequency equipment used in medical treatment. It was, of course, impossible to locate all such machines in the city in the time available, but those in charge of the few that were well known were consulted and promised to use their machines only when absolutely necessary during the week of the eclipse. The result was that the trouble was not serious though sometimes for short periods it was annoying. By careful manipulation of the relative phases of the time sweep and the commutator controlling the transmitter, the peak representing the reflected signal on the cathode ray oscillograph screen could be made to come between two of the peaks caused by the interference. Hence the reflection could usually be detected with fair certainty in spite of the interference, but height measurements were sometimes impossible.

Results

Nature of the Upper Layer Apart from Eclipse Observations

Owing to the effect of the magnetic storm on the few days preceding the eclipse, one cannot draw curves representing either layer heights or penetration frequencies displaying conditions on an average undisturbed day and compare them with similar curves on the day of the eclipse. Of all observations taken, those on September 1 and 2, and a few obtained on August 26, are the only ones that show any similarity. These have been taken to represent average undisturbed conditions though they show a phenomenon which, as far as the author is aware, has not been noted before, *i.e.*, the appearance of a critical frequency at which no echo appeared, though echoes appeared from the same layer at both lower and higher frequencies. The existence of this phenomenon was not noticed until the day after the eclipse. The usual procedure in taking observations was to start at some frequency at which an echo was fairly certain, say 4.61 Mc.* (65 m.) and proceed to reduce the wave-length by steps of 2½ m. until the echo disappeared. Then the first point at which, after careful visual observation of the oscillograph, no echo was found was taken as the penetration frequency and the results plotted

* *Mc. means megacycles per second.*

as in Figs. 1 and 2. When the critical point was found, the wave-length was not usually lowered further. Hence in early observations this reflectionless frequency band may have been overlooked, though had it not been for the disturbed conditions, assumedly due to the magnetic storm on the few days before the day of the eclipse, this reflectionless band would, no doubt, have been discovered earlier. The best example is shown in the results for September 2 (Fig. 2).

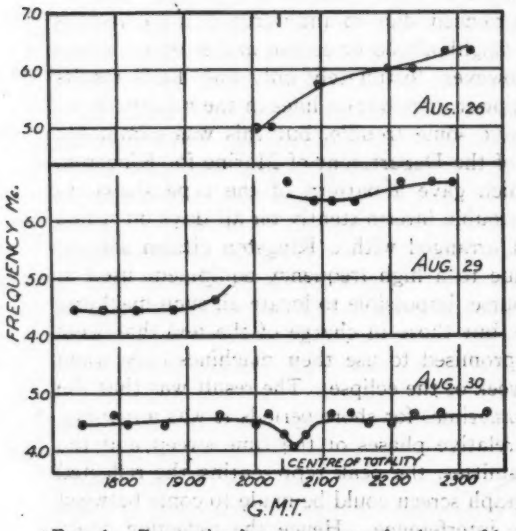


FIG. 1. *Penetration-frequency curves for August 26, 29 and 30.*

Examining the results for September 2, it is seen that, from the time observations started until about 2000 G.M.T. the penetration frequency was about 5.7 Mc. (52½ m.) but at the same time there was a band about 5.00 Mc. (60 m.) where no echo could be found. This condition altered at about 2000 G.M.T. and from then until the observations ceased echoes occurred at all frequencies below the penetration frequency, but there was a distinct difference in the appearance of the patterns at a frequency of 5.00 Mc. At this frequency the echo was split into several components, while echoes at frequencies below and above 5.00 Mc. were single sharp peaks. The points where these split echoes were found are marked with an X in Fig. 2, and the periods when the reflectionless band appeared are indicated with a broken line. Examples of the oscillograms showing the split and sharp echoes are shown in Plate I, examples Nos. 11 to 14. No. 11 shows a clear single echo. The frequency at which this oscillogram was taken was 5.46 Mc. (wave-length, 55 m.). Nos. 12 and 13

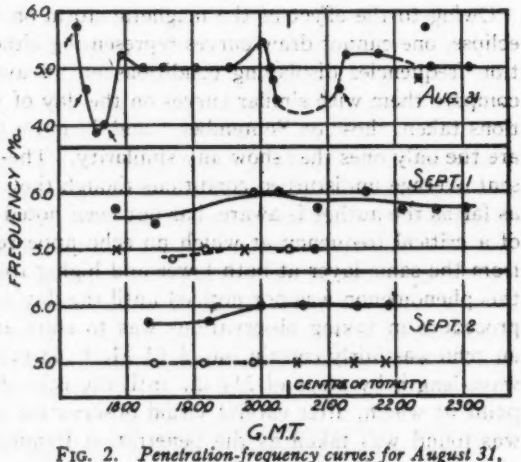
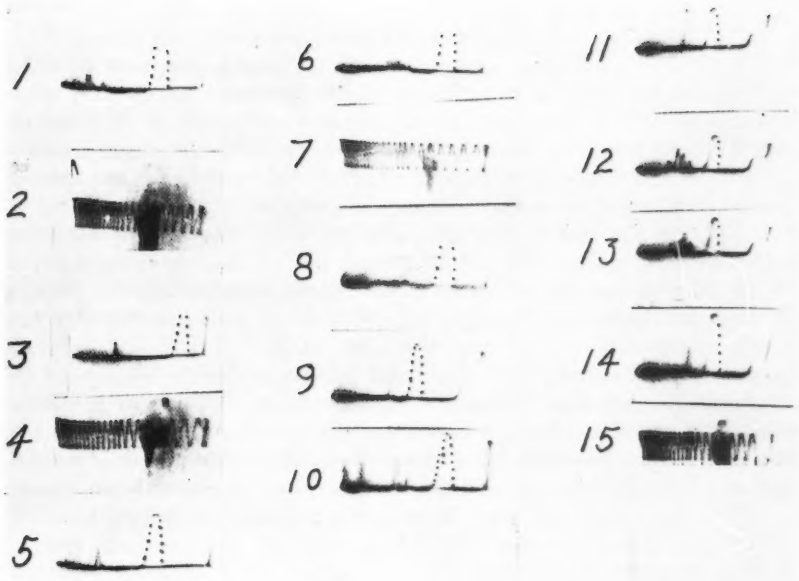


FIG. 2. *Penetration-frequency curves for August 31, September 1 and 2.*



Examples Nos. 1, 3 and 5 show echoes taken on August 29 at a frequency of 4.29 Mc. at 1839, 1852 and 1905 G.M.T., respectively. They are typical examples of unusually high equivalent heights found on that day. No. 2 is the time axis calibration for No. 3, and No. 4 the calibration for No. 5.

Examples Nos. 6 to 10 were taken on the day of the eclipse. No. 6 was taken at 2016 G.M.T. at a frequency of 4.14 Mc. Note the multiple splitting and haziness of the echo due to the constantly changing intensity of the components. No. 8 was taken a few minutes later and shows the effect of a thunderstorm. No. 9 was taken at 2140 G.M.T. at a frequency of 5.00 Mc. It shows a typical echo under steady conditions. No. 10 was taken one minute after No. 9 and indicates the effect of interference probably due to a high frequency machine for medical treatment (see page 19). No. 7 represents a time axis calibration for Nos. 6 and 8.

Examples Nos. 11 to 15 were taken on September 2. They are arranged to show the different type of echo at the frequency which, earlier in the afternoon was found to be reflectionless. No. 11 shows a sharp single echo at a frequency of 5.46 Mc.; Nos. 12 and 13 are examples of the multiple split echo at a frequency of 5.00 Mc. at which frequency no echoes were found before about 2000 G.M.T. (see page 20). Example No. 14 is a typical echo at a frequency of 4.61 Mc. No. 15 is a time axis calibration suitable to Nos. 11 to 14. Nos. 11 to 15 were taken between 2100 and 2200 G.M.T. on September 2nd.

The reproduction of the ground signal is not very good as the oscillograms showed it very faintly. To make it show up better the ground signal has been emphasized by a row of dots where necessary.

are examples of echoes at a frequency of 5.00 Mc. (60 m.). These two examples are the clearest obtained during all observations and are better than the average oscillogram. However, they show no great exaggeration of the effect noted, No. 14 represents a reflection at a frequency of 4.61 Mc. (65 m.). Again a single sharp echo is seen with a very weak echo due to double reflection.

On September 1 the results were not as definite as on September 2, but the same peculiarity was noted at about the same frequencies. Throughout the early part of the afternoon the reflectionless band appeared intermittently as indicated by the broken line and the split character of the echoes at intermediate points marked X was noted. Later in the afternoon the oscillograms showed the split echoes occurred at a frequency of 4.61 Mc. (65 m.), while at higher frequencies the echo was sharp. Frequencies lower than 4·61 Mc. were not tried, hence no points indicating split echoes are included in the curve after 2100 G.M.T. On August 26 this same phenomenon may have existed, as only two good points were obtained on the penetration-frequency curve before the time when reflections appeared consistently at 5.00 Mc., namely, 2000 to 2100 G.M.T. Higher frequencies were not examined at the times represented by these two points but if they had been the phenomenon indicated by the curves for September 2 might have been observed. On August 29, Fig. 1, the same may have been the case but if so the reflectionless frequency was lower. In the early part of the afternoon frequencies higher than 4.61 Mc. were not examined until shortly after 2000 G.M.T., as it was assumed that if no reflection occurred at 4.44 Mc. and at 4.61 Mc. the penetration frequency had been passed and it was pointless to proceed to higher frequencies. On August 30 the penetration frequency remained abnormally low all afternoon and it is unlikely that the reflectionless band discussed above occurred at all, because several times during the afternoon frequencies up to 5.00 Mc. were observed, the penetration frequency remaining at about 4.44 to 4.61 Mc. On August 31, the day of the eclipse, the reflectionless band was not observed though it may have existed at about 5.00 Mc., as observations were taken at higher frequencies only if a reflection occurred at this frequency.

The statement that this band exists, at which no reflection takes place, while echoes from the same layer are found at higher and at lower frequencies, is introduced with considerable reservation because the existence or lack of existence of an echo depends on the type of receiver and its surroundings. The critical penetration frequency of the upper layer has an arbitrary factor depending on the sensitivity of the receiver. In the present case observation of the cathode ray oscillograph screen appeared to leave but little doubt as to whether or not there was an echo. Though in many cases it was very small it was only rarely that the author had any doubt whether or not the echo existed. This would indicate either that the upper layer reflects an easily measurable signal or none at all; or that the receiver would indicate either an easily observable signal or none at all. As the sensitivity of the receiver

and oscillograph for weak signals was not studied in detail the arbitrariness in the penetration frequencies remains.

Another possible explanation of the existence of a reflectionless band might be that the energy in the echoes was absorbed by some resonance effect in the steel frame buildings in which the receiver was located, or between which the aerial was hung, or in the receiver itself. Similarly selective absorption may have been present in the neighborhood of the transmitter. Such effects, if they existed, did not show up in the reception of the ground wave. This point however is not very significant as the ground wave was very strong.

Neither the effects of neighboring buildings nor the lack of sensitivity of the receiver could account for the splitting of the reflected signal at certain frequencies while a sharp single echo was found at both higher and lower frequencies. That reflections at frequencies both higher and lower than the so-called reflectionless band come from the same region or nearly the same region is clear from the equivalent height curves for September 1 and 2 (Fig. 3), where heights for reflections at frequencies of 5.46 Mc. (55 m.) and 4.61 Mc. (65 m.) are shown. The reflectionless band was usually at 5.00 Mc. (60 m.). The differences in height are usually less than 100 km. and could be accounted for easily from the shape of the height-frequency curve given by Appleton and Naismith (3). The equivalent heights of reflections at 5.00 Mc. where found are rather erratic, and owing to splitting and general instability of the echoes are not sufficiently reliable to be shown by a curve which would mean anything. The heights are always measured from the first point of deviation of the ground signal from the time axis, to the corresponding point on the reflected signal. When the reflected signal is considerably split, the intensity of the various components is constantly varying, giving an effect on the oscillograph best described as "boiling". Very often the component of shortest delay may disappear for a few seconds. If a photograph is taken at this time the measured height may be abnormally high.

This frequency at which either no reflection from the upper layer appears or the reflected signal is split into several components should be investigated further. If after local effects are eliminated it still exists it may represent selective absorption in a lower layer, either the E layer or an absorbing but non-reflecting D layer as suggested by Appleton (1). The pattern presented when the reflection is split is not usually the simple form discussed by Eckersley (7) and by Appleton and Ratcliffe (4) as being the result of double refraction due to the effect of the earth's magnetic field. While sometimes only two peaks appear, usually several are seen constantly changing in intensity with no apparent relation to each other. This made such echoes difficult to photograph as exposures of about one-half second had to be used.

Effect of the Eclipse

The curve for August 31 in Fig. 2 and the curve in Fig. 4 represent the penetration frequencies and the effective height for a frequency of 4.61 Mc. respectively. It has been assumed, for reasons given above, that the results

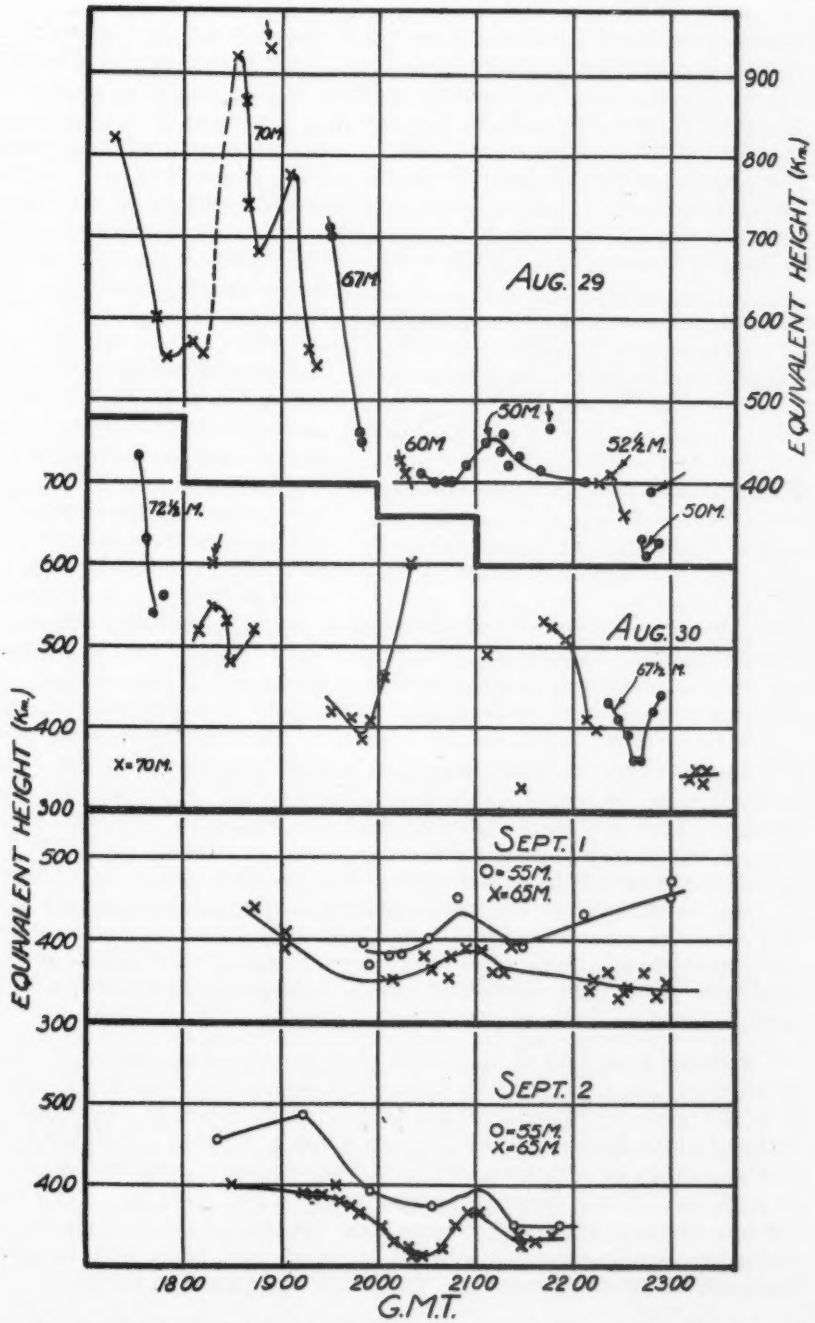


FIG. 3. *Equivalent heights of the upper reflecting layer at various wave-lengths on August 29 and 30, and September 1 and 2.*

of September 1 and 2 represent a normal undisturbed day, so the results of August 31 should be compared with these. First examining the relatively flat part of the curve representing penetration frequencies for August 31 between 1800 and 2000 G.M.T., it is seen that conditions do not appear to be quite like those on September 1 and 2. The penetration frequency during this period is somewhat lower on the day of the eclipse than on a normal undisturbed day, though as mentioned above the penetration frequency indicated may not have been the lower limit due to the possible existence of the reflectionless band. If this is the case the curve for the early part of the afternoon, neglecting the sharp depression between 1700 and 1800 G.M.T., compares well with the broken line on the curve for September 2. The sharp depression between 1700 and 1800 G.M.T. will be discussed later. Until about 15 min. before optical totality (approximately 2024 G.M.T.) the conditions were normal when at 2010 G.M.T., while working at a frequency of 5.00 Mc. the reflection suddenly disappeared and the penetration frequency dropped rapidly, a steady echo being found at 4.14 Mc. (72½ m.). Here the echo was split into a large number of peaks which were changing in intensity too rapidly to obtain a good photograph. A reproduction of such a reflection is shown in example No. 6, Plate I. The time delays of the most distant peaks found represent equivalent heights up to 800 or 1000 km. The broken line in the penetration-frequency curve in Fig. 2, August 31, is an estimate from visual observations of what was happening. Changes came too suddenly to obtain good points on the curve until about 2120 G.M.T., though one intermediate point at 2110 G.M.T., marked with an arrow head, is given, as the echo at this point appeared as though the frequency was very near the penetration point. At about 2020 G.M.T. a thunderstorm which could be seen some miles down the St. Lawrence river became active, making it additionally difficult to obtain oscillograms during this critical period.

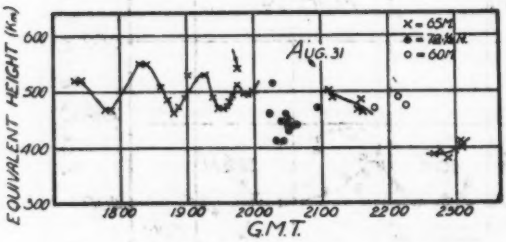


FIG. 4. *Equivalent heights of the upper reflecting layer on August 31.*

Conditions from 2120 G.M.T. until observations ceased, appeared to be quiet, except for a short period, indicating a penetration frequency of about 5.00 Mc. rather than about 6.00 Mc. as on September 1 and 2. The exception occurred a little before 2230 G.M.T. when echoes at 5.00 Mc., which had been coming steadily for some time, seemed to disappear and a small echo appeared at 5.46 Mc. (55 m.) disappearing again at 5.72 Mc. (52½ m.). This was the first discovery of the reflectionless band discussed in the previous section and even then its existence was not apparent until notes were carefully examined the following morning. The points are marked on the curve.

The nature of the transient penetrating frequencies at the time of optical totality is evidence that radiation from the sun, presumably ultra-violet light, has a decided effect on the ionization of the upper reflecting layer. The curves representing the variation in height are not so conclusive, largely because the unstable state on the few days before the eclipse, lasting until the day of the eclipse, has left an insufficient knowledge of normal conditions for comparison. The equivalent height at a frequency of 4.61 Mc. (65 m.) is somewhat higher on the day of the eclipse than on the two succeeding days, which have been taken as normal. During the eclipse period, echoes at this frequency disappeared, though the equivalent height of the layer for a frequency of 4.14 Mc. (72½ m.) does not appear to be abnormal.

The relation between ionization and penetration frequency used by Henderson (8), indicates that the density of ionization is proportional to the square of the penetration frequency. In the present case the stoppage of radiation from the sun by the moon reduced the density of ionization of the upper layer by 30% or more.

An effect due to the corpuscular eclipse predicted by Chapman (6) should be at its maximum at about two hours before optical totality. That would be between 1800 and 1900 G.M.T. The results on the day of the eclipse indicate no abnormal effects at this time, though there was an abnormality between 1700 and 1800 G.M.T. This peak shown on the penetration-frequency curves for August 31 is taken to be due to the continued activity of the magnetic storm, rather than an indication of an effect due to a corpuscular eclipse, for two reasons. First, it is not unlike a similar abnormality on the preceding day; second, not only does it occur an hour too soon, but Kingston is well outside the region where any corpuscular eclipse was predicted. (See the map on page 35.)

If the above interpretation of this abnormality between 1700 and 1800 G.M.T. is accepted, the results definitely indicate that the ionization of the upper reflecting layer is caused to a considerable extent by radiation from the sun, though it will be seen in the next paragraphs that there are other phenomena, presumably magnetic storms, which have a considerable effect on the nature of this layer.

Effect of Magnetic Storms

The unstable effects noted on the few days before the eclipse are attributed to the magnetic storm, because it is known that magnetic storms have an effect on radio reception and a magnetic storm was reported as starting on Saturday, August 27, and being at its height on August 29 and 30. (See report of the Canadian Marconi Company on trans-Atlantic reception in the succeeding paper (9)). The effect of this magnetic storm on the upper reflecting layer of the earth's atmosphere is indicated by abnormally low penetration frequencies and unstable effective heights. An examination of the penetration frequency curve for August 29, Fig. 2, shows that early in the afternoon the penetration frequency was abnormally low. At about 1930 G.M.T. observations were stopped for about 25 min. and when started

again it was found that a transition had taken place, the penetration frequency having risen to such an extent that a point was not obtained on the curve until about 2030 G.M.T. From this time until observations ceased the penetration frequency was found to be about 6.5 Mc. This value is slightly higher than that for September 1 and 2, the days which have been assumed to be normal.

It may be that the first part of the curve for August 29 is not the true penetration frequency but represents a reflectionless band of the type found on September 1 and 2, occurring at about 4.5 Mc. instead of 5.00 Mc. as on the latter days. The true limit may have been missed because, once it was noted with certainty that the reflection had disappeared, observations were not made at higher frequencies. On August 30 the penetration frequency was abnormally low all afternoon with an exceptionally low point due to some disturbance at about 2030 G.M.T. On this day there was no evidence of a reflectionless band as frequencies from 5.00 Mc. to 4.00 Mc. were observed periodically throughout the run.

The existence of the discontinuity in the penetration-frequency curve for August 29 and the depression in the curve for August 30 were rather disconcerting in view of the fact that they came very near the time of totality. Indeed there is nothing to indicate that the depression in the penetration-frequency curve for August 31 at the time of the eclipse was due to the eclipse rather than the magnetic storm, except that conditions on the eclipse day were more nearly normal and the time and length of period of the disturbance coincided with the expected effect, when one considers that there should be a lag of several minutes due to the slow rate of recombination of ions in the reflecting layer. The depression in the penetration-frequency curve for August 31 between 1700 and 1800 G.M.T. is considered to be due to a further vagary of the magnetic storm. The points marked with an arrow on this curve are somewhat uncertain because a rapidly changing penetration frequency made it impossible to obtain points quickly enough.

The height measurements on August 29 and 30 are very erratic. Owing to the abnormal penetration frequencies, frequencies which could be compared with those for the normal days September 1 and 2 were not used. Hence in the equivalent height curves in Fig. 3 for August 29 and 30 an attempt was made to plot equivalent heights at frequencies slightly lower than the penetration frequency (usually 2½ or 5 m. longer wave-length). The wave-lengths at which observations were taken are given on the curves in each case. Blank periods occur where information was lacking or where the penetration frequency was changing too rapidly for a series of observations at any one wave-length. Sometimes, owing to a lacking first component of a split reflection, exceptionally high equivalent heights are recorded. Such points are marked with an arrowhead on Fig. 3.

Summarizing the results of August 29 and 30 it can be said that the magnetic storm appeared to produce periods during which the ionization in the upper layer was abnormally low and the equivalent heights exceptionally high,

heights around 900 km. often being recorded. A sample of some of the records is shown in Plate I, examples Nos. 1 to 5.

Summary of Conclusions

The conclusions drawn from observations on reflections of radio waves from the upper ionized layer of the earth's atmosphere are that this ionization is caused at least in part by radiation from the sun, presumably ultra-violet light. This was demonstrated by the fact that about 15 min. before totality the penetration frequency (the lowest frequency which goes through the layer without reflection) dropped considerably, coming up again to its normal value at about three-quarters of an hour after totality. The lag in the effect or the lack of symmetry with respect to time, about the centre of totality, was expected, due to the time required for recombination of ions as the sun's rays were cut off and the forming of the layer as the sun's rays reach it again. This lag also tends to make it uncertain whether or not the ionization of the upper layer is entirely due to radiation from the sun. A decrease in ionization of over 30% was observed.

During the three days before the eclipse a magnetic storm which was known to be in progress had very noticeable effects on the upper ionized layer. The effect was a reduction in the density of ionization and unusually high but very unstable equivalent heights.

On the two days after the eclipse, which, owing to the effect of the magnetic storm had to be considered as normal undisturbed days, a new phenomenon was noted. At certain times of the day there appeared to be a frequency at which no echo was found, while echoes from the same region appeared at both lower and higher frequencies. When an echo did appear at this so-called reflectionless frequency it was split usually into several components, while echoes at lower and higher frequencies usually consisted of a single clear component. Lack of measurable echoes at a certain frequency might be due to local causes but no explanation is given for the selective splitting.

Acknowledgment

It was originally intended that the station in Kingston should have been in charge of Lieutenant-Colonel W. A. Steel, assisted by the author. About two weeks before the eclipse Colonel Steel was called to the International Radio Conference at Madrid but most of the preliminary planning, collecting and testing of equipment, was carried out by him. The author wishes to express his thanks to Colonel Steel for the way in which the preliminary work was completed, leaving little to be done but the setting up of the equipment in Kingston and the taking of the observations. Thanks are also due to Queen's University, particularly the Electrical Engineering staff; and to the Royal Military College, particularly the staff of the Physics Department, for the use of their laboratories, and their assistance. The observations were taken with the assistance of Staff-Sergeant C. M. Wright of the Royal Canadian Signals and Mr. Roy Burstow of the National Research Labor-

atories and thanks are due to them for the reliable way in which they carried out the work. Thanks are also due to the Associate Committee on Radio Research of the National Research Council of Canada under whose jurisdiction all radio observations were carried out.

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FADING AND SIGNAL-STRENGTH MEASUREMENTS TAKEN DURING THE SOLAR ECLIPSE OF AUGUST 31, 1932[1]

By J. T. Henderson[2] and D. C. Rose[3]

Abstract

This paper contains the results of observations on signal strength and fading, taken during the total solar eclipse of August 31, 1932, by the Canadian Marconi Company, the Northern Electric Company, the Marine Department of the Canadian Government and l'Ecole Polytechnique, Montreal.

The Canadian Marconi Company at Yamachiche took signal-strength observations on trans-Atlantic and American short-wave stations. The Northern Electric Company measured field strengths in Montreal from the Ottawa station in the broadcast band (600 Kc.). The stations of the Marine Department in the Hudson Strait and Hudson Bay regions and also in the Newfoundland and Nova Scotia region took notes on short-wave reception from Ottawa and direction-finding bearings on specified nearby stations. L'Ecole Polytechnique had a receiving station at Rigaud, Quebec.

The results of observations on short waves indicate no effect at the time of the predicted corpuscular eclipse, but a definite night effect at the time of optical totality. Direction-finding stations and observations on the broadcast band report no effect.

This report embodies the results of the radio observations made during the eclipse by the Canadian Marconi Company, the Northern Electric Company, l'Ecole Polytechnique, Montreal, and the radio stations of the Marine Department of the Canadian Government. The writers' present herewith the individual reports sent to Dr. A. S. Eve, the chairman of the Radio Eclipse Subcommittee of the National Research Council. The reports received are reproduced wholly or in part and such conclusions as appear to be justified are drawn.

Short-wave Reception across the Atlantic

The report received from the Canadian Marconi Company on reception across the Atlantic and from some stations in Canada and in the United States is best explained by publishing it as it was received:—

Canadian Marconi Company

Report on Signal-strength Observations during Solar Eclipse August 31, 1932

Program

It was arranged to take signal-strength observations during a period of four hours on the day of the eclipse, and during the same period for the preceding two days as well as the day after the eclipse, the observations to commence daily at 1830 G.M.T. and end at 2230 G.M.T. The time of totality of the eclipse at Yamachiche, P.Q., was approximately 2024 G.M.T.

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Observations

The observations were carried out at the Marconi trans-Atlantic receiving station at Yamachiche, P.Q. This station is located well within the path of totality. The stations observed included European trans-Atlantic telegraph and telephone stations as well as a few North American stations operating in the short-wave band.

The measurements were made in relative values calibrated in decibel gain or loss.

Receiving Conditions During Tests

Unfortunately, receiving conditions were poor during the first two days of the tests and all trans-Atlantic circuits observed were affected by a magnetic storm which had been in process since Saturday, August 27.

During August 29 and 30 the effect of the magnetic storm was sufficiently serious to prevent observations of any value. Conditions during August 31, the day of the eclipse, were moderately good.

On September 1 a local electrical storm occurred during the four-hour period and observations were again impossible.

Results of Observations

Table I gives the relative values of the observations taken on various short-wave stations during the four-hour period on the day of the eclipse.

The field intensity of most of the short-wave European transmissions showed no wide variation during the four-hour period. Comparisons made between the results of these observations and the observation records kept daily at the receiving station on the majority of these stations show that the relative strengths as given in Table 1 are, in general, normal for the particular time of the day and for the particular receiving conditions at the period.

In the case of Station WDD, located at Long Island, New York, U.S.A., our records show that signals from this station usually fall in strength at approximately the same time as the decrease in intensity occurred on the day of the eclipse.

The reception from Station CGA at Drummondville on 62.71 m. showed no change in signal strength during the four-hour period on August 31. The distance between this station and the receiving station is only of the order of 30 miles. The observations were taken on the ground-ray signal.

In the case of Station VE9GW located at Bowmanville, Ontario, the observations show a large fall in signal strength on the day of the eclipse, commencing at 2005 G.M.T. and continuing until 2030 G.M.T. A slow increase in intensity then occurred. Observations made on this station from 1700 to 0200 G.M.T. on several days during September when receiving conditions were normal showed no such decrease in intensity occurring at that particular period. An average of the measurements taken on these days gives the following results:—

1700 G.M.T.	+ 7 D.B.	2200 G.M.T.	+ 18 D.B.
1800	+ 11	2300	+ 18
1900	+ 13	2400	Nil
2000	+ 15	0100	Nil
2100	+ 17	0200	Nil

TABLE I

SIGNAL-STRENGTH OBSERVATIONS, SOLAR ECLIPSE, AUGUST 31, 1932, TAKEN AT YAMACHICHE SHORT-WAVE RECEIVING STATION

DB VALUES ARE ABOVE OR BELOW A REFERENCE LEVEL OF SIX MILLIWATTS (ZERO LEVEL)

G.M.T.	GBB 13585 Kc.	GLH 13535 Kc.	GNH 11580 Kc.	FTL 9970 Kc.	GOK 9260 Kc.	GLK 8005 Kc.	WDD 7510 Kc.	VE9GW 6095 Kc.	CGA 4765 Kc.
1830	—	−10	−10x	24	—	−10	18	8	8
1835	—	− 7	−10x	14	—	− 6	18	8	8
1840	—	− 8	−10x	24	4	− 6	18	8	18
1945	2	− 9	−10x	22	—	−10	18	8	18
1950	−19	− 9		22	− 2	− 6	18	8	14
1855	−20	− 9	−10x	14	− 6	−10	18	6	16
1900		− 6	−10x	14	− 6	−10	18	6	16
1905		− 6		14	− 4	Stops	18	8	16
1910	−10	− 8		14	−10	trans-	18	6	16
1915	−18	−10		14	− 8	mit-	18	6	18
1920	−18	−10	−10x	16	− 4	ting	18	6	16
1925	− 8	−9	−10x	16	− 2		18	6	18
1930	6	−9	−10x	16	0	− 8	14	6	16
1935	2	−6	− 8	10	0	− 8	14	8	14
1940	0	−6	−10x	16	2	−10	14	6	16
1945	4	−7	−10x	20	2	−10	0	8	16
1950	4	−5	−10x	16	0	−10	0	8	18
1955	6	−6	−10x	16	2	−10	0	8	16
2000	4	−4	−10x	16	0		−7	10	18
2005	6	−2	−10x	16	4	4	−18	− 2	18
2010	6	−1	−10x	20	8	4	−7	− 2	20
2015	6	−1	−10x	20	14	12	−7	− 6	16
2020	6	−2	−10x	20	14	18	−7	− 8	22
2024		−2	−10x				−7		
2025	6			22	14	18	−7	−16	22
2028							0		
2030	6	−2	−10x	22	14	18	6	−20	20
2035	8	−2	−10x	22	14	18	6	−16	18
2040	8	−2	−10	16		14	10	−10	16
2045		0	−10	16	Stops	10	10	− 2	16
2050	4	0	−10	16	trans-	12	10	− 2	16
2055	2	2	− 9	16	mit-	6	10	− 4	20
2100	0	2	− 9	22	ting	12	10	− 2	20
2105	−4	2	− 9	22		12	10	2	18
2115	−2	2	−10x	22	8	18	10	4	22
2125		1	−10	22	12	18	18	4	22
2135		1	−10	22		18	Change	4	22
2145			− 9	20		12	wave-	4	20
2155			−10x	16		12	length	4	18
2205			−10x	16		12		4	18
2215				16		12		8	12
2225				20		12		4	12

NOTE: −10x *indicates less than* −10 DB. *Plain figures are plus.*

GBB	Rugby, England. 13585 Kc. 1500 Cycle tone.
GLH	Dorchester, England. 13535 Kc. High speed telegraphic traffic to N.Y.
GNH	Grimsby, England. 11580 Kc. High speed telegraph to Australia.
FTL	St. Assise, France. 9970 Kc. Telegraph.
GOK	Bodmin, England. 9260 Kc. 1000 Cycle tone.
GLK	Dorchester, England. 8005 Kc. High speed telegraph to New York.
WDD	New York. High speed telegraph to Yamachiche.
VE9GW	Bowmanville, Ontario. Musical program.
CGA	Drummondville, Quebec. 1000 Cycle tone.

This station continues operating up to 0300 G.M.T. but is not received at Yamachiche Station from 2400 G.M.T. onwards, possibly due to an increase in skip distance. Normally, therefore, the results produced by the so-called "night effect" on reception of Station VE9GW at Yamachiche receiving station is a complete fade-out of signals.

Summary

The occurrence of either the corpuscular or the optical eclipse gave little or no effect on reception, carried out at the Marconi station at Yamachiche, P.Q., of transmissions received from various European stations operating in the short-wave bands.

Reception from Station VE9GW located at Bowmanville, Ontario, approximately 336 miles from the receiving station, showed a decided drop in field intensity occurring 19 min. before the time of the optical solar eclipse and continuing until 6 min. after totality. A gradual increase in intensity to normal was then observed.

No such similar occurrence is experienced normally on transmissions from this station, except during the night period, when signals completely fade out.

Reception on the Broadcast Band between Ottawa and Montreal, carried out by the Northern Electric Company

The report of the Northern Electric Company is as follows:—

Report on Eclipse Measurements by the Northern Electric Company

At the request of Dr. Eve, Chairman, Associate Committee on Radio Research of the National Research Council of Canada, measurements were made at the Shearer Street plant of the Northern Electric Company in Montreal to study fading on the day of the total solar eclipse and for several days previous to, and on the day following, the eclipse.

Inasmuch as the centre of the shadow during the eclipse in the 100-km. Kennelly-Heaviside layer was located about midway between Montreal and Ottawa, it was thought that radio waves originating in Ottawa might be reflected by this layer so as to be received in Montreal and observed with regard to fading. Furthermore, the shadow in the 200-km. Kennelly-Heaviside layer being beyond Ottawa, reflection effects from this layer would not be involved.

Beginning on Saturday, August 27, and ending on Thursday, September 1, a daily record on a recording milliammeter was made at Montreal of the field strength of CNRO, the 500-watt broadcasting station, at Ottawa, of the Canadian National Railways. These measurements were made daily from 1 p.m. to 9 p.m. standard time. The results obtained on the days preceding the day of the solar eclipse failed to show any appreciable change in signal strength between day and night radio reception. It was considered that this was due to the predominance of the ground wave for the transmission distance

(about 170 km.) and transmission frequency (600 Kc.) involved, so that substantial variation, if present, in the downcoming waves did not appreciably affect the total intensity of received signal. This stability of received signal for day and night reception indicated the unlikelihood of any appreciable variation being observed in signal strength on the day of the eclipse. This surmise proved to be correct for, on the day of the eclipse, the record was substantially the same as for the days preceding and on the day following the eclipse.

Incidentally, an attempt was made to record the signal strength of CKCO, a 100-watt radio station at Ottawa transmitting on 890 Kc. It was thought that this station, being on a shorter wave-length, would have a relatively larger downcoming wave component, but unfortunately the power output of this station was not sufficient to permit of distinct reception above the prevailing noise level. Accordingly, no useful data could be obtained from signal-strength measurements on this station.

The apparatus set-up used to measure the field strength variations of CNRO is roughly outlined as follows: A loop antenna consisting of 15 turns was mounted on the roof of the Shearer Street plant, and was connected to measuring apparatus located in the shielded room of the Radio Laboratory by means of a shielded pair. The loop was tuned to resonance by means of a variable condenser and the shielded pair was connected to ¼ turn tapped off from the centre of the loop. An attenuator and a coupling circuit were connected in circuit between the incoming shielded pair and the grid of the first tube of the short-wave tuned radio-frequency radio receiver used in the set-up. A milliammeter inserted in the plate lead of the automatic gain control circuit of the radio receiver furnished an indication of the variation in received signal strength, while a recording milliammeter in series with this meter furnished a permanent record of the signal variations as a function of time. A signal generator was available for alternative connection to the receiver input in order to provide a signal of known intensity: this alternative connection was involved in a determination of the received signal strength in microvolts per metre corresponding to the readings of the recording milliammeter. The received signal strength from CNRO was found to be approximately 600 microvolts per metre.

Direction Finding and Short-wave Reception Observations taken at Various Stations in Northern and Eastern Canada

The program of observation undertaken by the Marine Department stations was as follows: from August 29 to September 2 inclusive, direction-finding signals were to be sent out from Nottingham Island and Canso daily between 1500 G.M.T. and 2300 G.M.T. Two-minute signals were sent out on the hour and every 15 min. throughout the period with the following variations: on August 31 a five-minute test was to be sent out at 2000 and 2040 G.M.T. and continuous signals were to be sent between 2010 and 2035 G.M.T. The wave-length of signals used was 800 metres.

Stations in the Hudson Bay and Northern regions were to take DF bearings on Nottingham Island and stations on the east coast on Canso. Besides this a short-wave and long-wave watch was to be kept on signals from Ottawa (22-metre band). Stations were particularly asked to watch for night variations.

No pronounced night effect on direction-finding observations is reported from any of the stations, either in the northern (Hudson Bay and Hudson Strait) or the eastern (Nova Scotia and Newfoundland) regions at the time of the optical eclipse or the predicted corpuscular eclipse. It should be noted that atmospherics were very heavy on the day of the eclipse due to local thunderstorms around the gulf of St. Lawrence.

Stations reporting DF observations are:—

Cape Hopes Advance Churchill Resolution	From Nottingham Island.
St. Paul Island Cape Race Yarmouth Chebucto Head St. John	From Canso.

These (except Churchill, which is on the southwest shore of Hudson Bay) are marked on the map (p. 35).

On the other hand, reports from Marine Department stations on short-wave receptions show more definite results. Cape Hopes Advance reports as follows: "Hopes Advance nil heard till 2034 signal strength R 2 slight fading. McLean 2005, R 4, then gradually decreased until at 2014, R 1 to zero, then gradually increased till 2023 when R 7, again decreasing till 2030 when R 3 to R 2, then increasing rapidly to Rs at 2035. Considerable QRN noticeable during first part of test decreasing at 2020". (Time G.M.T.) Note the violent fading after the time of the optical eclipse. (Eclipse at this point was 90% total at 1955 G.M.T.)

The above report covers reception from Ottawa on 22-metre band by Cape Hopes Advance and SS. N. B. McLean in position indicated on map. The signal-strength levels are conventional levels from 1 to 10 and are estimates made by operator from the loudness of the signal in the phones.

The following is reported from the Experimental Farm in Ottawa:—

CNR Rabat Morocco, 23-Metre Band. Normally R 5 to R 3 during early afternoon, gradually increased in strength reaching R 9 plus for about 10 min. between 3.30 and 4.20 p.m. and gradually diminished until R 5 about 5 p.m.

IAC Coltano Italy, 23-Metre Band. Normally R 4 to R 3 showed a similar effect to Rabat also reaching R 9 maximum between 3.20 p.m. and 4.20 p.m.

KPH Bolinas Col., 23-Metre Band. Usually not heard until 4 p.m. when he begins coming in in R 2, was heard working R 5 to R 4 at 3.03 p.m. and continued throughout afternoon.

Times indicated are Eastern Daylight Saving time (maximum eclipse at about 4.24).

FIG. 1.

From Moose Jaw, Sask., the following extract was received: Amateur stations from districts W1, W2, W3 and W4 were very distinct on 40 metres at 1310* August 31, while the 20-metre band was dead. It would appear by this condition that the eclipse had considerable effect on short-wave signals as conditions at this period were completely reversed. The above districts are never heard during daylight at this location, whereas 20-metre signals at this hour are usually good. No effect was noticed on the lower frequencies.

Districts W1, W2, W3, and W4 cover roughly the eastern third of United States.

Stations of the Marine Department reporting short-wave reception are:—

Cape Hopes Advance, SS. N. B. McLean, from Ottawa, 22-metre band.
Experimental Farm Ottawa, from Morocco, Italy and California.
Moose Jaw, Sask., from Eastern United States.

** 1310 local time is 2010 G.M.T.*

The following is a summary of some observations taken at Rigaud, Quebec:—

A party from the Engineering Department of l'Ecole Polytechnique in Montreal, under the direction of Professor J. A. Villeneuve, set up a station in Rigaud. Their object was to measure the height of the ionizing layers, but owing probably to oscillograph and transmitter trouble, their results on height measurements are inconclusive. They did, however, report that at the time of the optical eclipse they noted a sudden and rapid increase in received signal strength from stations a thousand miles away. This increase was noted at various wave-lengths between 20 and 80 metres.

From the evidence of short-wave reception it would appear that night-time or a partial return to night-time conditions prevailed during the optical eclipse, but there seems to be no indication in the reports of any effect occurring about the time of the predicted corpuscular eclipse. Reflection of these wave-lengths occurs in the F region, so any increase in strength may be a decrease in ionization and consequent decrease in absorption of the signal in the E or lower ionized region.

Conclusions

From the above observations it seems unlikely that there was any effect that could be ascribed to the predicted corpuscular eclipse, but it must be noted that many of the stations were not suitably situated for the observation of such effects. Cape Hopes Advance and McLean are probably the best situated with regard to place, but owing to their high latitude and the consequent low elevation of the sun they are not much better.

At the time of the optical eclipse more pronounced effects were found, the best example being the reception of Bowmanville at Yamachiche, by the Canadian Marconi Company, in which the transmission was directly across the path of optical totality. Although the trans-Atlantic transmissions are somewhat conflicting no great importance is attached to the decrease in signal strength at about 1900 G.M.T. of signals coming from GBB and GOK (see report of the Marconi Company). The Marconi Company seemed to consider that it was probably an aftermath of magnetic storms recorded prior to the eclipse.

All the above work gives corroborative evidence of the results in the two previous papers (1, 2), namely, that the ionization definitely decreases at the time of optical totality, and all results seem to support our conclusions that there was no corpuscular eclipse within the territory of our observations.

Acknowledgments

We wish to thank the Canadian Marconi Company, The Northern Electric Company, l'Ecole Polytechnique, and the Marine Department, for kindly giving us the results of their measurements.

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THE WIND TUNNEL DEVELOPMENT OF A PROPOSED EXTERNAL FORM FOR STEAM LOCOMOTIVES[1]

By J. J. Green[2]

Abstract

The existing shape and arrangement of steam locomotives are such that smoke from the stack tends to sweep back along the boiler top and descend in front of the cab windows, seriously impairing forward vision. For the maximum degree of safety it is essential that the view from the cab, especially in a forward direction, should be unobstructed at all times. It is therefore desirable that some means be found for improving the manner in which the smoke is carried away from the stack. In addition to preventing the descent of smoke at the cab it is desirable that the external shape of the locomotive should be so modified as to result in a decreased air resistance, in view of the growing demand for economical running at increasingly higher speeds.

The paper describes work done in the wind tunnel of the National Research Laboratories and discusses the steps whereby an improved external shape has been evolved for locomotives such that the smoke is lifted over the cab thus making possible an unimpaired vision ahead.

The new design is the result of the application of elementary aerodynamics to the problem and aims at providing smoother air flow about the locomotive. Further, a layer of clean air is introduced between the smoke and the body of the locomotive and is responsible for maintaining the smoke above the cab. By removing the violent eddying flow about the locomotive the air resistance of the engine and tender has been reduced to the extent of some 35%.

Introduction

It is an unfortunate feature of the steam locomotive in its present state that the exhaust steam and smoke have to be emitted at a position some distance ahead of the cab. In recent times sporadic and inadequate attempts have been made to improve conditions for the engineer. With the development of higher-powered locomotives, the shorter stacks have increased the problem of lifting the smoke clear of the cab. When the locomotive is drifting, the absence of the exhaust steam jet in the stack allows the smoke to pour down over the top and sides of the boiler, seriously impairing vision from the cab windows (Figs. 8 and 9). This trouble is serious and may lead to accidents when the locomotive is approaching a station. If it is possible to lift the smoke well clear of the cab, it is quite likely that it will remain above the train so that the quantity of smoke and cinders entering the coaches will be reduced. No recent scheme for curing this trouble has been sufficiently successful to merit general adoption. A number of odd-shaped devices have been attached to the front of the boiler and the stack, but their lack of success is due to the fact that the aerodynamics of the entire locomotive is involved, particularly the front and upper surface of the boiler. Marshall (3) believes that the smoke trouble is caused by the "hollow space over the tender". This may be so in British practice, but the argument fails for Canadian and American locomotives where the "hollow space" is absent. The work done by Chapelon (1) at St. Cyr Aerodynamic Institute in 1928 is noteworthy.

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A $\frac{1}{10}$-scale model "Pacific" type locomotive was tested for the Orleans Company. Moving pictures were taken of the air and smoke flow as indicated by woollen streamers and magnesium oxide powder and the effect on smoke removal of various attachments was studied. Chapelon inferred from his work that devices placed round the stack were useless, but that lateral guard-screens at the front end of the boiler were effective in transforming the eddying flow about the locomotive into streamline flow. (Compare the effect of the Townend ring cowling (6) on air-cooled radial aero engines.) The Canadian National Railways and a number of other roads have experimented with deflectors at the stack, but they have not given satisfaction, as Chapelon predicted. Side guards have been used in England, but no information appears available as to their utility.

In the work which follows, it was hoped that radical changes in the entire locomotive shape would yield considerable improvement in smoke flow and resistance. It was felt that the use of side guards was an attempt to improve slightly what is already a very poor aerodynamic shape. Wind tunnel tests (Fig. 10) substantiate the statement that the entire upper surface of a modern locomotive is shrouded in eddies due to poor aerodynamic design. These eddies behind the stack, dome and valves trap the smoke which is then comparatively slowly dissipated since the eddies reduce considerably the average air velocity over the boiler. This retarding of the flow adjacent to the boiler is further enhanced by the crude shape of the boiler front. Removal of the smoke nuisance by changes in design which will give smooth high speed air flow over the boiler top and sides will obviously produce at the same time a reduction of the air resistance of the locomotive, and in recent times the reduction of running costs by minimizing air resistance has been slowly coming to the forefront. Work at the National Physical Laboratory for the L.M.S. and L.N.E.R. railways (2), and that of Tietjens (4, 5), may be cited as being typical of the attention being devoted to air resistance.

Air resistance at low or medium speeds is small in comparison with other sources of resistance and the locomotive itself has only about 30% of the total air resistance of the train. Since, however, the air resistance increases as the square of the speed, whereas other resistances rise only as some power of the speed less than unity, it is evident that, for the high speed passenger services nowadays common to railroad practice, air-resistance reduction merits attention in the quest for economy.

Nature and Scope of the Tests

In 1931 the Canadian National Railways requested the National Research Council to undertake an investigation of the above-mentioned problems with a view to improving their high speed locomotive design. A $\frac{1}{12}$-scale model of the 6100 class engine and tender (Fig. 2), complete in every detail and constructed mainly of steel, was forwarded for use in the wind tunnel tests. The open tunnel with a jet 9 ft. in diameter, 13 ft. long and a maximum speed of 160 m.p.h. was eminently suitable for the work to be done.

A number of restrictions were imposed on the work at the outset; for example, owing to legal restrictions, certain features such as a bell, whistle, stairways at front and runways at sides cannot be eliminated, although their disposition might be changed. Further restrictions arose from the fact that the same general shape, sizes and clearances and operating arrangements were to be retained, and that definite accessibility for connecting rods, valve motion, axles and axle boxes was required. Despite the great saving in air resistance, no cowling could be tolerated over this mechanism, and the fire-box had to be left free to prevent blocking of the air-opening into the ash pan. Other structural limitations were imposed by the restricted position and height above the water level in the boiler of the feed-water heater. Clearance for the water supply pipes also limited the level of the top of the water tank. Finally all modifications were to be such as could be done economically and easily, with the bare minimum of alteration to the locomotive itself, and this practical aspect has been kept in mind throughout the work.

In view of the difficulty of extensive alteration to the scale model supplied, without damaging it, a wooden model was made to the same dimensions, reproducing all the main essentials, without the minor details (Figs. 2, 4 and 5). Both models were tested for resistance, and the ground effect on the steel model was measured both with a dummy ground and by utilizing the wooden model as a mirror image (Fig. 2).

The wind speeds employed in the tests ranged up to 170 ft. per sec., and above speeds of 30 or 40 ft. per sec. no scale effect existed, that is, the resistance coefficient obtained by dividing the resistance by the square of the wind speed is a constant within the limits of practical measurement. This linear variation of resistance with the square of the speed allows prediction of the full-scale locomotive resistance with greater assurance of accuracy.

Resistance Measurement

The method initially employed for measuring resistance was to suspend the model by wires and observe its "swayback" in the wind, computing the resistance from the observations. The drawbacks to this method were that the model oscillated considerably rendering observation difficult, the computations were laborious, and in the case of the wooden model it was necessary to load it with lead weights to limit the "swayback", which increased the number of wires in the jet and complicated the oscillation of the model.

In view of these objections, a rough subframe drag balance was built above the jet. The force on the model was transmitted by suspension and bracing wires to the subframe and thence to the scale pan of an accurate balance. Ground effect was supplied by a dummy ground (Fig. 4) supported beneath the model, just clear of the wheels.

Air Flow Around the Model

The velocity vectors of air currents around the model, with its various modifications, were studied by means of silk streamers attached to a grid

of very fine wire suspended just above the locomotive, and another just in front of the model. Additional threads were attached along the boiler sides and in front of the cab window. These threads proved very sensitive to changes in shape of the locomotive and were satisfactory in indicating the beneficial effect or otherwise of any specific modification, and in addition they were easily photographed for purposes of recording the air currents existing around the body of the model (Figs. 10 and 20).

All tests were done at zero yaw since the effect of side wind on a high speed locomotive is considered to be small, in so far as air resistance is concerned, and the results of the work were to be applied to high speed runs at maximum speeds in the neighborhood of 80 m.p.h. Very little room exists for improving the aerodynamic characteristics of railway coaches and since the air is excessively turbulent by the time the last coach is reached, it is doubtful if a special streamlined observation car at the rear end would be worthy of consideration. For these reasons and also because of the predominating importance of the smoke problem, no work was done on reducing train resistance.

The silk threads indicated the exceptionally poor airflow round the existing type of locomotive (Fig. 10) and showed how the general flow is deflected downwards all along the boiler sides. The existing shape of cab causes the air to pour down in front of the cab windows, and leaves no doubt as to the likelihood of their being obscured when the locomotive is drifting in the manner shown in Figs. 8 and 9.

General Outline of Results

By progressive steps there has been developed for the locomotive an improved shape which operates primarily by inducing a layer of pure air to enter under the smoke layer, such that a space enveloping the boiler and extending well above the top of the boiler is fed continuously with air uncontaminated by smoke. The construction of the model is such that this smoke-free layer is retained beneath the smoke with a minimum of intermingling of the two. Smooth entry for this clean air is effected by a new design for the locomotive front end. At the position of the cab further quantities of smoke-free air are induced upward in front of the cab windows, to augment the layer of pure air immediately above the locomotive. Here originally existed a downward current of smoke which necessitated the provision of a grating on the running board in front of the cab window, to allow for the disposal of the cinders collecting there.

The modifications to effect this change of flow result in a reduction of approximately 35% of the air resistance of the locomotive. The best model tested reduced the air resistance by 43%, but the cowling employed interfered with the accessibility required for the working parts.

Description of Tests and Results

Preliminary measurements of wind resistance were made with the $\frac{1}{72}$-scale model. It was suspended at the centre of the wind tunnel jet by means of

eight wires (four 12-gauge wires to the locomotive, and four 16-gauge wires to the tender) attached at their lower ends to steel stirrups passing under the boiler and water tank of the model. The upper ends of the wires were fastened to steel I-beams on the platform above the jet. The wires were all identical in length and were arranged to be vertical. The ends of the wires at the model as well as at their upper attachments were pin-jointed. A steel scale graduated in hundredths of an inch was fastened horizontally on the side of the boiler as shown in Fig. 2. This steel scale was observed through a telescope set up at the side of the jet, and for each wind speed employed the "swayback" of the model was observed through the telescope. The method used for computing wind resistance can be followed by reference to Fig. 1.

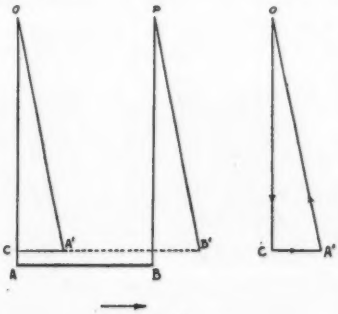


FIG. 1.

Let AB represent the model suspended by parallel wires of equal length, OA, PB, in a wind whose direction is indicated by the arrow. Suppose the model sways back to a position $A'B'$. Equilibrium of the system is determined by the weight of the model, the air resistance or drag, and the tension in the supporting wires. $OA'C$ is the triangle of forces where the length OC is proportional to the total model weight W, and the length $A'C$ is proportional to the resistance R. ($OA = OA' = PB$ = length of supporting wires measured from pin joints at each end.)

Let $D = A'C$ the amount by which the model has swayed back.

Then $OC = \sqrt{(OA')^2 - D^2} = \sqrt{(OA' + D)\ (OA' - D)}$.

Now $\frac{R}{W} = \frac{A'C}{OC}$ or $R = \left(\frac{D}{OC}\right) \times W = \frac{D}{\sqrt{(OA + D)\ (OA - D)}} \times W$.

Knowing W and OA and measuring D, it is possible to calculate R, the wind resistance.

Table I gives the results for the metal model for which the total weight, W, was 318.75 lb. The length of suspension wires was 11 ft. 11⅜ in.

The resistance coefficient in the last column includes the air drag of the supporting wires. The existence of scale effect is seen at speeds below about 40 ft. per sec. where the value of $\frac{R}{V^2}$ changes with V. Above this speed the value of the resistance coefficient is reasonably constant within the limits of experimental accuracy.

Assuming then that the resistance coefficient $\frac{R}{V^2} \times 100$ is the same for full scale as at the higher speeds in the model tests, the full-scale resistance at

any wind speed V ft. per sec. is derived by multiplying the value of $\frac{R}{V^2}$ by $V^2 \times \left\{\frac{1}{\text{model scale}}\right\}^2$, so that for a $\frac{1}{12}$-scale model the multiplying factor will be $(V^2 \times 144)$, the relative resistances of model and full scale being in the ratio of their frontal areas.

TABLE I

RESULTS OBTAINED WITH THE METAL MODEL

Wind speed, V, ft./sec.	Amount of swayback, D, in.	$\sqrt{(OA + D)(OA - D)}$	Wind resistance, R, lb.	Coefficient $\frac{R}{V^2} \times 100$
20	0.24	143.375	0.534	0.133
30	0.55	143.374	1.223	.136
40	1.00	143.372	2.223	.139
50	1.56	143.366	3.468	.139
60	2.28	143.357	5.070	.141
70.4	3.12	143.341	6.938	.140
79.8	4.01	143.319	8.918	.140
90	5.14	143.283	11.434	.141
100	6.38	143.233	14.198	.142
110.5	7.77	143.164	17.300	.142
120	9.14	143.084	20.361	.141
154	15.12	142.575	33.750	.142
170.2	18.08	142.230	40.455	.140

Correction of Results for Drag of Supporting Wires

The reaction at the locomotive due to the wire-suspension drag is given as a contribution to the total resistance measured in the tests, and must therefore be deducted in order to evaluate the resistance of the locomotive and tender alone. Since the curve relating to the resistance of wires, their diameters and wind speed is well known, the value of the resistance of those lengths of the suspension wires included by the air jet was easily calculated for each wind speed used in the tests, and the necessary correction applied.

This gave a mean value of $\frac{R}{V^2} \times 100 = 0.1135$ for the model alone over the the range of speeds for which the coefficient is constant, R being in lb. and V in ft. per sec.

Ground Effect

The resistance measurements on the metal model were not as yet applicable to actual practice in view of the fact that the model had been freely suspended, and the presence of the ground in full scale had not been allowed for.

Two methods suggested themselves for introducing ground effect. It is well known that the effect of a boundary surface on the air flow past a body in its neighborhood is the same as if the boundary was replaced by a second model so placed with respect to the first as to constitute a "mirror image"

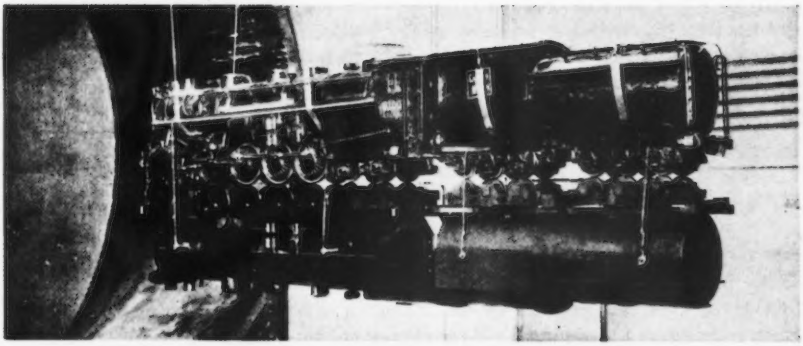


FIG. 2. *Model of C.N.R. 6100 class locomotive and tender ($\frac{1}{12}$-scale) suspended in wind tunnel jet with wooden dummy to give ground effect.*

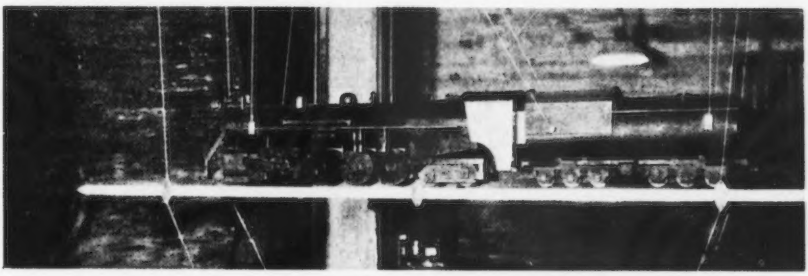


FIG. 4. *Wooden model with dummy ground suspended in wind tunnel.*

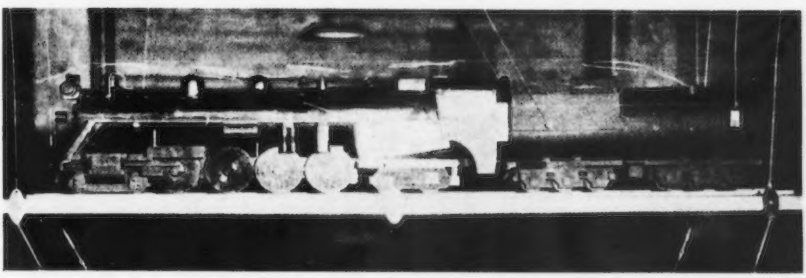


FIG. 10. *Air flow over unmodified model as indicated by silk threads. Wind speed, 45 m.p.h.*

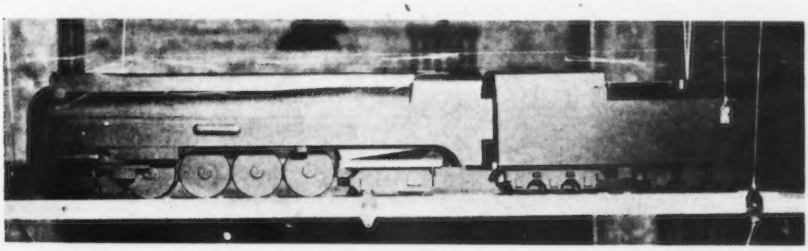


FIG. 20. *Air flow over modified model as indicated by silk threads. Wind speed, 45 m.p.h.*

of the first model in the boundary. The wooden model was then used in the first method for determining ground effect. Fig. 2 shows the two models under test. Knowing the resistance of the metal model freely suspended and subsequently measuring the resistance of the wooden model freely suspended, the sum of these two resistances exceeds the resistance of the combined pair by an amount which represented the effect of the ground. Assuming this effect to work equally on both models, half the effect gives the individual ground interference on any one model.

It was found that the ground effect was such as to reduce the resistance of the locomotive and this becomes obvious when it is considered that the action of the ground is such as to retard the air passing underneath the model.

The second method of evaluating ground effect was to suspend a dummy ground underneath the model, just clear of the wheels, and to measure the resistance of the model with this ground in place. Such a method produces results which are directly applicable to the case of a full-scale locomotive running on the tracks, and by evaluating the difference between these results and those for the freely suspended model, a second estimate of the ground effect could be made and compared with that derived by the use of a "mirror image".

Results

Speed range 0 to 175 ft. per sec.

Mean coefficient of resistance for metal model freely suspended,

$$\frac{R_s}{V^2} \times 100 = 0.1135.$$

Mean coefficient of resistance for wooden model freely suspended,

$$\frac{R_w}{V^2} \times 100 = 0.1062.$$

Mean coefficient of resistance for combined pair freely suspended,

$$\frac{R_s + R_w - 2d}{V^2} \times 100 = 0.2054,$$

where d is the interference effect on each model due to the ground. By addition a set of values for $\frac{R_s + R_w}{V^2} \times 100$ over the speed range are calculated and by subtracting the corresponding values of $\frac{R_s + R_w - 2d}{V^2}$ a set of values for $\frac{2d}{V^2} \times 100$ are derived. The results gave a mean value for $\frac{d}{V^2} \times 100$ of 0.0067, as the interference effect on each model due to ground.

Correcting the resistances of the two models for ground effect, the resistance of the wooden model, including ground effect, is given by

$$\frac{R}{V^2} \times 100 = 0.0995,$$

the resistance of the metal model, including ground effect, is given by

$$\frac{R}{V^2} \times 100 = 0.1068,$$

R in lb. and V in ft. per sec.

These values are obtained by subtracting the ground effect,

$$\frac{d}{V^2} \times 100 = 0.0067,$$

from the resistance coefficient for each model freely suspended.

The full-scale locomotive resistance at V m.p.h. is then given from the results with the steel model as

$$R = \frac{0.1068}{100} \times \frac{88^2}{60^2} \times 144\ V^2 \text{ lb.},$$

or

$$R = 0.3308\ V^2 \text{ lb.}$$

Measurements with a Subframe Drag Balance

Fig. 3 shows the general arrangement of this drag balance. The subframe is constructed of angle iron welded together, and is suspended from two vertical frames which will be designated by the terms upstream and downstream.

The downstream frame supports the subframe on two knife edges, whereas the upstream frame supports the subframe on a single cone pivot. At its upper end, the downstream vertical frame is suspended from two knife edges, the V-blocks being fixed on the upper flanges of two longitudinal I-beams resting on the balance platform. The upstream vertical frame is likewise pivoted on two knife edges located on the upper flanges of the I-beams. This upstream frame is also fitted with sensitivity weights at its upper end, and is arranged to transmit the horizontal drag force as a vertical force acting on the scale pan of a Dayton balance. The four upper knife edges from which the two vertical frames are suspended are all in one plane. Similarly the two knife edges and cone pivot on which the subframe rests are all in another plane.

The horizontal spacing of these points of support is the same in both planes and the vertical spacing is the same at the upstream and downstream frames. By virtue of this the subframe remains horizontal as the balance swings, and the two vertical frames remain parallel as they swing out of the vertical. The balance includes a dash pot for damping oscillations.

The ratio of the moment arms is such that the balance indicates 1.83 times the drag force on the model.

The first test made with the subframe drag balance was to repeat the measurement of the resistance of the wooden model freely suspended with no ground effect included, the idea being to check the agreement between the subframe balance measurements and those made by observing swayback.

After correcting for wire drag, the resistance, R lb., of the freely suspended wooden model was found to be given by $\frac{R}{V^2} \times 100 = 0.1068$, compared with 0.1062, the value deduced from swayback measurements.

The wooden model was initially suspended from the subframe by four 12-gauge wires and four 16-gauge wires and by removing these in pairs, making resistance measurements after each removal until only two wires of each gauge remained, it was possible to deduce an experimental value for the

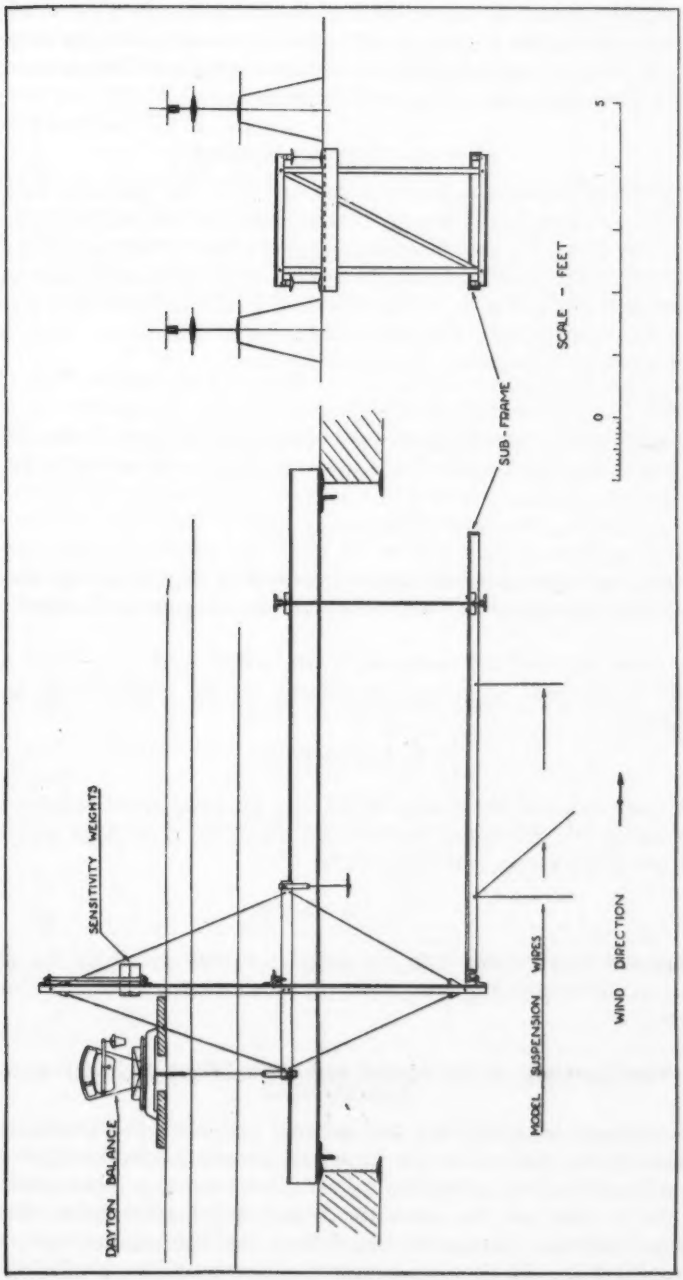


FIG. 3. *Diagram of the subframe drag balance.*

wire-drag contributions. Since these included the turnbuckles incorporated in the wire suspension system, in correcting the readings for the drag of the remaining wires it was preferable to use these experimental corrections rather than the theoretical corrections used heretofore.

Use of a Dummy Ground

Fig. 4 shows the wooden model suspended from the subframe balance by four 16-gauge wires, and braced by two inclined wires of very small diameter. The dummy ground is shown in place; it was made to be over twice as wide as, and considerably longer than, the model, and was braced rigidly by wires attached as shown in Fig. 4. It was provided in side elevation with a rounded nose and a tapering tail, and was rectangular in plan form. This dummy ground was used throughout the remaining work.

Results

The mean value over the speed range 0 to 130 ft. per sec. of the resistance R lb. of the wooden model with dummy ground present was found to be given by

$$\frac{R}{V^2} \times 100 = 0.1089,$$

where due correction has been made for the drag of the vertical suspension wires, but no allowance has been made for the drag of the inclined bracing wires.

The mean value of the resistance of the model, with no ground present, over the same speed range and uncorrected for the inclined wire drag was found to be

$$\frac{R}{V^2} \times 100 = 0.1149.$$

The mean value of the ground effect over the same speed range, obtained by averaging the differences between the two sets of readings whose mean values are given above, was found to be

$$\frac{d}{V^2} \times 100 = 0.0066,$$

which agrees very closely with the value of 0.0067 found by the previous method for determining ground effect, in which a mirror image of the model was used.

Modifications of the Model and their Effect on Resistance and Air Flow

The problem of modifying the external shape of the locomotive was simplified by the realization that improved air and smoke flow goes hand in hand with reduced air resistance. Features on existing locomotives which upset the air flow are the feed-water heater and number lights, the dome, valves and turrets, the poorly shaped front and the exposed valve motion and running gear. All these contribute to the resistance by producing eddies.

The first modifications were made with a view to reducing wind resistance by improving the airflow about the sides and top of the locomotive, and these will be considered in the order in which they were made and numbered accordingly. Fig. 5 shows the wooden model before modification. All details are not included in this drawing.

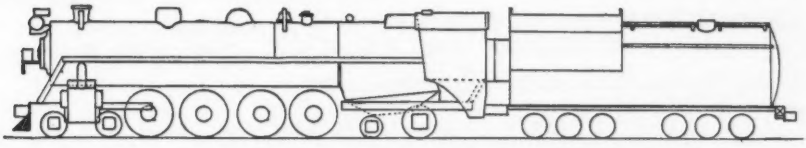


FIG. 5. *Drawing of original model unmodified.*

(1) *Side curtains on the locomotive.* In order to shield the cylinders, valve motion, running gear, etc., side curtains were fitted to the model below the running boards and extending down to the level of the bottom of the cowcatcher (see Fig. 6). These side curtains reached from the cowcatcher or pilot to the rear of the locomotive cab and were made of sheet metal. A solid wooden pilot was made to replace the normal type and a sloping sheet metal front extending from the top of the pilot to the bottom of the smoke box was incorporated. The reason for these changes was to prevent air from entering underneath the locomotive through the cowcatcher bars or just below the

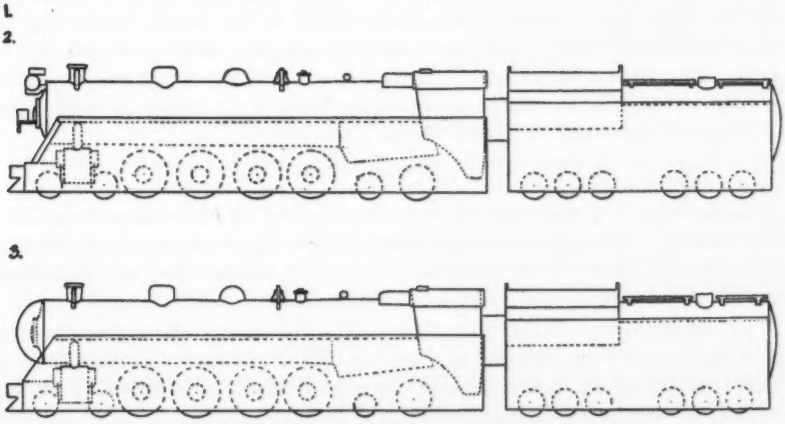


FIG. 6. *Drawings of model incorporating modifications 1, 2 and 3.*

boiler. By thus shielding the running gear both by the side curtains and by so closing the front below the boiler as to exclude air, it was hoped that wind resistance could be reduced and a smoother flow achieved for the air passing along the sides of the locomotive.

The wind speeds employed in this and subsequent tests were 20, 40, 60, 80, 100, 120 and 130 ft. per sec., but the average values only of the resistance

divided by the square of the wind speed have been presented here. Due correction has been made for the drag of the vertical suspension-wires but no allowance has been made for the relatively smaller drag of the two inclined bracing wires, owing to the difficulty of correcting for them. In view of their small effect, and since also the tests were designed to measure differences arising from modifications, in which case wire drag balances out completely, this correction was deemed unimportant.

Drag of original unmodified model R lb. at V ft. per sec. given by

$$\frac{R}{V^2} \times 100 = 0.1089.$$

Drag of model with side curtains on locomotive and solid pilot, etc., as outlined above given by

$$\frac{R}{V^2} \times 100 = 0.1088.$$

At first sight this result was disappointing but it was seen on further consideration that the effectiveness of any particular modification in reducing resistance would depend very considerably on the extent to which other changes had been already made to reduce resistance. It was argued that adding side curtains to an otherwise unchanged model would produce only a very small change in resistance, whereas their effect on a model which had been carefully streamlined elsewhere would be very considerable indeed. This argument was completely vindicated by subsequent tests.

(2) *Side curtains on the tender.* Leaving the model already modified as above, sheet metal side curtains were added to the tender extending from runways to the same lower level as those on the locomotive and reaching from front to rear of the tender (see Fig. 6). Their object was to close in the curved sides of the water tank and the frame and axle boxes of the tender.

Drag of the model so modified was given by

$$\frac{R}{V^2} \times 100 = 0.1036.$$

This indicates a greater saving than that effected by the side curtains on the locomotive. This saving, it is argued, would not be so appreciable had the side curtains been absent from the locomotive and would have been greater still had the rest of the model been streamlined.

(3) *Modifications to the boiler front.* The feed-water heater, headlamp and side staircases were removed and an approximately hemispherical front was fitted to the smoke box, otherwise the model was as modified in (1) and (2). A diagram of the model thus modified is given in Fig. 6.

The changes were intended to provide smooth flow over the locomotive front and to remove obstructions likely to disturb this flow.

Drag of model given by

$$\frac{R}{V^2} \times 100 = 0.0763.$$

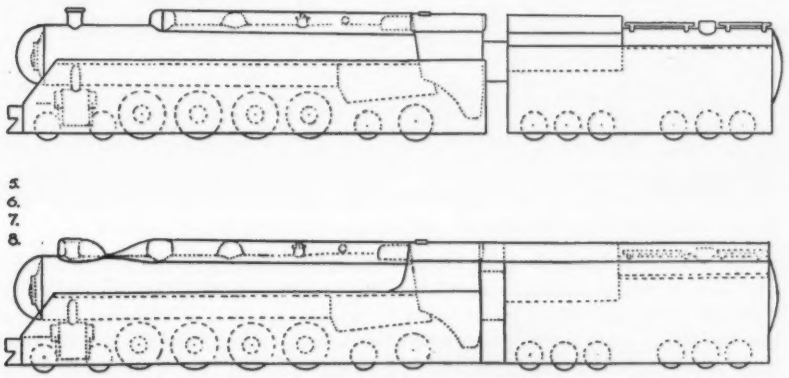
This represents some 30% saving in resistance on that of the original model. The feed-water heater was suspected of causing considerable disturbance to smooth flow and its removal undoubtedly accounts for part of the reduction

in drag. The curved nose on the front of the smoke box ensures smooth flow initially which offsets the disadvantages of bad shape met with subsequently. It is well known that changes to the front of a body have considerable effect on the flow around it and, although this is usually applied to the treatment of streamlined bodies, it appears in some measure to be true of such a poor aerodynamic shape as a locomotive.

(4) *Modifications to the top of the boiler.* With the model as already modified, the following changes were made.

The whistle and bell were removed and a metal cowling flush with the centre of the cab roof and having the same roof contour but vertical sides was fitted over the turrets, valves and dome, extending forward to the centre of the sand dome, as shown in Fig. 7.

4.



5.
6.
7.
8.

FIG. 7. *Drawings of model incorporating further modifications 4, and 5, 6, 7, 8.*

These changes were intended to remove the eddying flow over the upper surface of the boiler due to obstructions presented by the various items located on the boiler top.

Drag of the modified model given by

$$\frac{R}{V^2} \times 100 = 0.0710.$$

This modification was expected to be very beneficial as regards smoke removal by introducing smooth flow conditions behind the stack, the reduction in resistance being evidence of the removal of the eddying flow.

(5) *Modifications to the stack region.* The front of the metal cowling over the turrets, valves and dome was sloped down in a gentle curve to the top of the boiler just behind the stack and a streamlined tail was added to the stack (see Figs. 7 and 23). This latter modification was intended to reduce wind resistance as well as providing what is important from the point of view of smoke removal, *viz.*, smooth flow round the stack and an absence of an eddying region behind the stack.

Drag of the model is given by

$$\frac{R}{V^2} \times 100 = 0.0698,$$

a saving in resistance being effected as anticipated.

(6) *Modifications to the tender.* A cowling conforming to the cab roof was fitted over the entire tender, with the object of removing the space between the cab roof and the first coach roof caused by the lower level of the top of the water tank. This cowling is depicted in Fig. 7.

Drag of the model is given by

$$\frac{R}{V^2} \times 100 = 0.0666,$$

a reduction in resistance resulting from removal of the depression behind the coal bunker where eddying of the flow was occurring.

(7) *Cab modifications.* The gap between the cab and tender was closed by a cowling flush with the sides and roof of the cab as shown in Fig. 7.

Drag of the model given by

$$\frac{R}{V^2} \times 100 = 0.0666.$$

Closing in this gap had absolutely no effect on resistance. In view of this fact it appears useless to attempt to reduce train resistance by closing the gap between coaches, and more so, since the air is more turbulent by the time it reaches the coaches.

(8) *Cab modifications.* As already indicated the slope of the cab front is such as to create a down draught of air at the cab window. To avoid this the cab front was filled in to slope backwards from the running board and the overhang of the cab roof was eliminated. Generous fillets and curves were employed to eliminate corners and sharp edges, and a generous smooth curve between running board and cab front was considered necessary. This modification is shown in the lower drawing of Fig. 7.

It was intended that air taken from the sides of the boiler above the running boards should be shot upwards in front of the cab windows to keep them clear.

Drag of the model was found to be given by

$$\frac{R}{V^2} \times 100 = 0.0620,$$

indicating that a considerable reduction in resistance results from these simple modifications to the cab.

The combined effect of all the foregoing modifications was thus found to produce a 43% reduction in the air resistance of the original model.

Having gone as far as possible in removing the smoke trouble by improving the design of the locomotive from an aerodynamic standpoint, it remained to examine the flow of air over the original model and over the modified model, in order to see how successful this improvement was as regards smoke removal, and to add any special devices or modifications in order to increase the effectiveness of the new shape in keeping the smoke from the cab windows.

Investigation and Improvement of the Smoke Flow

For the purpose of examining the flow around the model a number of methods were considered before the final decision to use silk streamers was made. The use of titanium tetrachloride for exhibiting the flow and allowing photographs to be made would have been ideal but for the fact that the corrosive vapor formed by it could not be tolerated. The use of metal sheets painted with kerosene and lampblack placed round the model

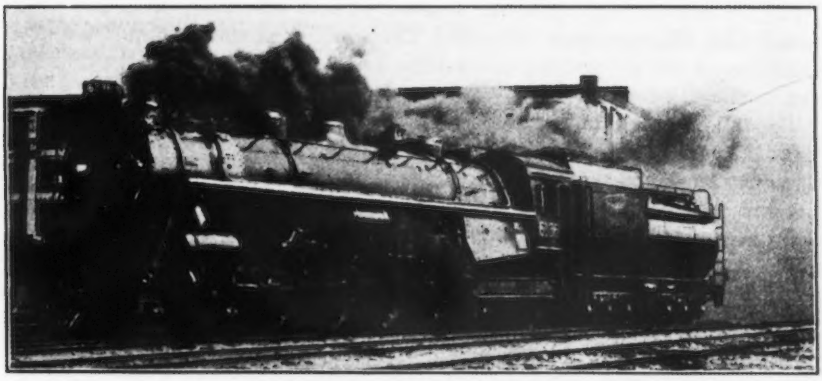


FIG. 8. *C.N.R. 6100 locomotive drifting, showing poor flow of smoke.*

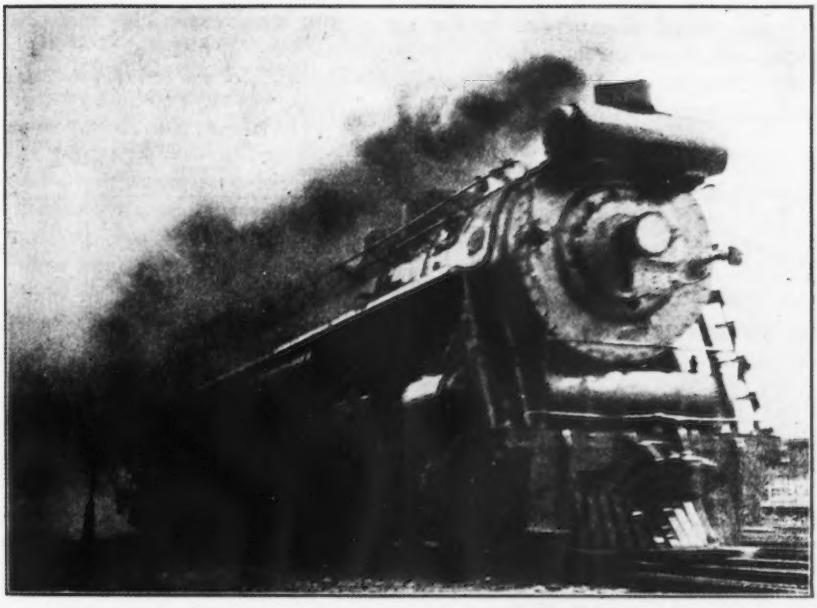


FIG. 9. *C.N.R. 6100 locomotive drifting, showing cab window obscured by smoke.*

in the plane in which the flow is to be investigated was considered but not employed, owing to the inevitable distortion of the flow by the metal sheet coupled with the fact that only the flow adjacent to the metal sheet is exhibited.

In Figs. 8 and 9 the flow of smoke from the stack of a C.N.R. 6100 engine is shown when the locomotive is drifting. It can be seen from these photographs how the smoke clings to the top of the boiler and blows down round the cab window.

Fig. 10 is a photograph of the original wooden model set up in the wind tunnel with silk streamers attached. The wind speed was 45 m.p.h. and the directions of the air currents around the model are indicated by the disposition of the silk threads.

The following deductions are clearly indicated by the photograph:—

(a) The large eddy behind the smoke stack, caused partly by the feed-water heater, traps the smoke from the stack in the manner shown by the streamer attached to the top of the stack.

(b) A region of eddying flow occurs behind the dome, turrets, etc., on top of the boiler, shown by the streamers attached to these portions of the locomotive.

(c) Considerable downward flow occurs along the boiler sides, exhibited by the streamers attached to the side of the boiler at the dome and at the bell.

(d) A considerable down draught of air occurs at the cab window, shown up clearly by the two threads attached to the boiler side at this position.

In Fig. 11 a drawing has been made of the air flow around the partially modified model as exhibited by the use of silk streamers. The following important points are indicated:—

(a) There is no eddy behind the stack; the thread from the top of the stack trails out behind with a slight upward trend.

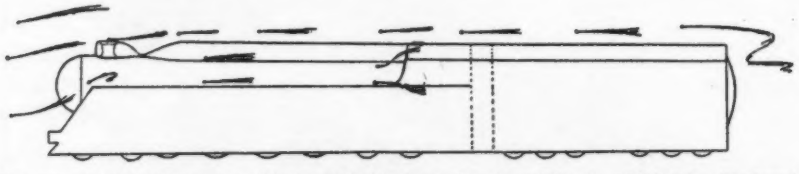


FIG. 11. *Type of flow over model as modified in lower drawing of Fig. 7, exhibited by silk threads.*

(b) Steady smooth flow conditions exist over the top of the boiler.

(c) There is no downward flow along the boiler sides.

(d) The flow over the cab window is mainly upwards although slight downward flow occurs where the cab front meets the running board, and a slight tendency exists for the air to spill round the sides of the cab.

It is obvious that the flow over this model represents a considerable improvement over the original type of flow, although room still remains for improvement at the cab and at the stack if the smoke is to be positively lifted clear of the locomotive.

Special Modifications for Removing the Smoke

(9) *Changes to stack region.* In order to keep the smoke layer from blowing down into contact with the top surface of the locomotive, an attempt was made to collect a volume of pure air from in front of the stack and to discharge it behind the stack, underneath the smoke layer. The first attempt to do this was made by extending forward the cowling which covered the dome, turrets, etc., so that it reached past the smoke stack to the front of the boiler where it was left open to catch air. The smoke stack just protruded through the top of this cowling and a slot was cut in this new portion of the cowling where it butted on to the old cowling in order to allow exit for the air caught in front of the stack. These changes are shown in Fig. 12 (upper drawing).

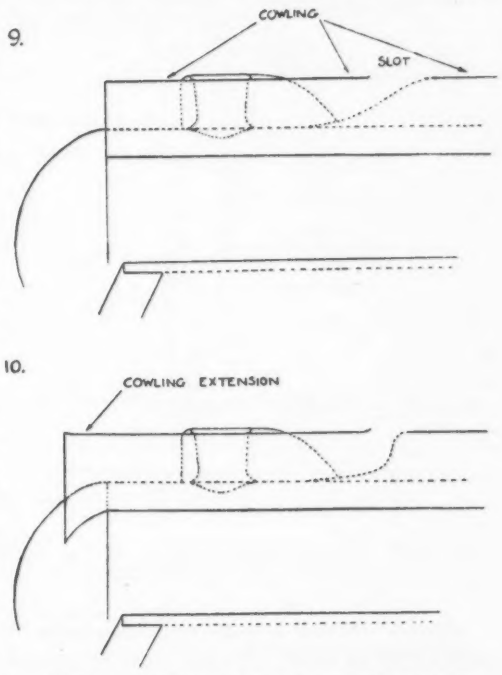


FIG. 12. *Drawings of model incorporating further modifications 9 and 10.*

This arrangement was only moderately successful. The smoke layer was indeed lifted by the introduction of a clean air layer between it and the locomotive, but not to the extent desired.

(10) In order to catch a greater volume of air the cowling was extended forward some two inches and its sides dropped down to the rounded nose of the boiler as shown in the lower diagram of Fig. 12. The two sides of the cowling were opened out to give a flared entrance. The rear surface of the slot which ran in a smooth surface from the top of the old cowling to the boiler top behind the stack was modified to give a greater upshoot to the air discharged from the slot.

These changes produced an improved flow. The streamers indicated the existence of a very strong ascending air current from the slot behind the stack.

(11) *Cab front modifications.* To prevent the spilling of air round the sides of the cab, side plates were fitted to the cab such that they protruded forward some short distance from the cab front. These side plates in conjunction with the boiler sides formed scoops in front of the cab windows (see Fig. 13), which functioned by shooting the air upwards over the windows. These side

plates improved the flow by eliminating both the slight down trend of the air near the running board and the spilling round the cab sides.

It was felt that the flow over this model was satisfactory and a series of measurements of its wind resistance were made at various speeds to see what effect these changes had made on drag.

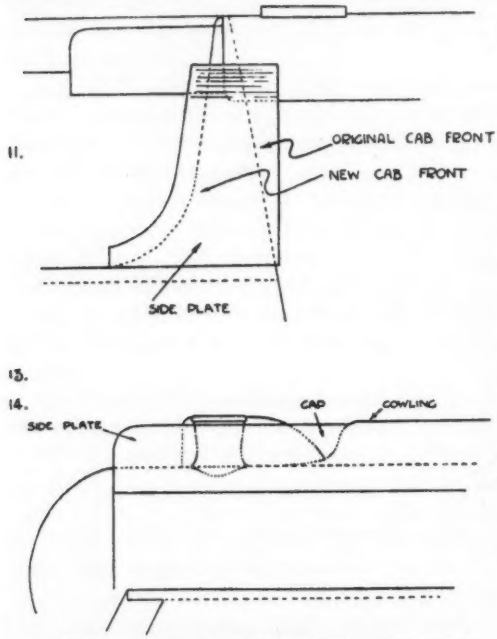


FIG. 13. *Drawings of model incorporating further modifications 11, 13 and 14.*

The results gave a mean value of

$$\frac{R}{V^2} \times 100 = 0.0727.$$

It is evident that the special modifications made to lift the smoke at the stack had considerably increased the air resistance of the model. It was assumed that the extension to the cowling had disturbed the flow over the round nose of the model and caused the sudden rise in resistance.

(12) Accordingly the model was changed by removing the 2-in. extension added in 10.

Drag of the model was then given by

$$\frac{R}{V^2} \times 100 = 0.0685.$$

(13) Leaving the sides of the extended cowling untouched on either side of the stack, the model was modified by removing the roof of the cowling forward of the slot as in Fig. 13 (lower drawing). The idea here was to remove the interference of the roof over the passages on either side of the stack. It was felt that it merely retarded the pure air layer and contributed nothing to the scheme.

Drag of the model was then found to be given by

$$\frac{R}{V^2} \times 100 = 0.0665.$$

With these modifications the air flow was found to drop slightly just behind the stack before finally ascending over the cowling.

(14) The length of the gap between the streamlined tail of the stack and the curved surface leading to the top of the cowling was reduced in order to remove the sudden drop of the flow just behind the stack. This was successful. Fig. 13 (lower drawing) shows this modification.

(15) The front ends of the running boards were rounded off to remove the eddies formed by the sharp corners and side plates were added to act as

scoops, as shown on the left in Fig. 14. This improved the flow, lifting it all along the boiler sides, but the resistance was increased.

Drag of the model was given by

$$\frac{R}{V^2} \times 100 = 0.0798.$$

This large increase in drag was caused by the side plates giving rise to large eddies in the flow round the sides of the model.

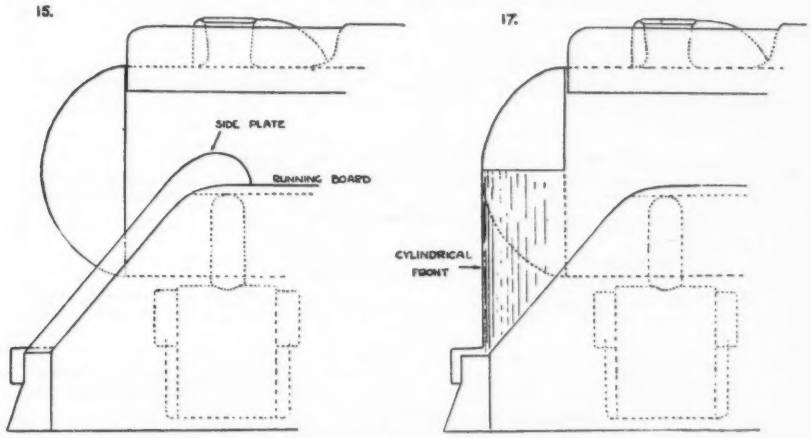


FIG. 14. *Drawings of model incorporating further modifications 15 and 17.*

(16) Removed side plates, running boards left rounded at their front ends. Drag given by

$$\frac{R}{V^2} \times 100 = 0.0654,$$

restoring the resistance to a figure approximately the same as that before the addition of the side plates at the front ends of the running boards.

(17) *Changes to the boiler front.* A cylindrical surface was added between the rounded nose of the boiler and the sloping front, as shown on the right in Fig. 14. The intention was to provide smooth flow conditions for the air entering the space above the running boards along the boiler side.

Drag given by

$$\frac{R}{V^2} \times 100 = 0.0647,$$

indicating a slight reduction in air resistance due to smoother flow conditions.

(18) *The tender.* In view of the operating restrictions cited in the introduction the tender could not be fitted with a cowling over the water tank, and runways had to be left at the sides of the coal bunker. A cowling conforming to the cab roof was left over the coal bunker.

Drag of model was then given by

$$\frac{R}{V^2} \times 100 = 0.0633.$$

(19) *Side curtains.* Operating restrictions will not at present tolerate the complete closing in of valve motion, cylinders, running gear, axles, etc., and for this reason the side curtains had to be cut down in size to leave exposed the several places where inspection and servicing are required. To examine

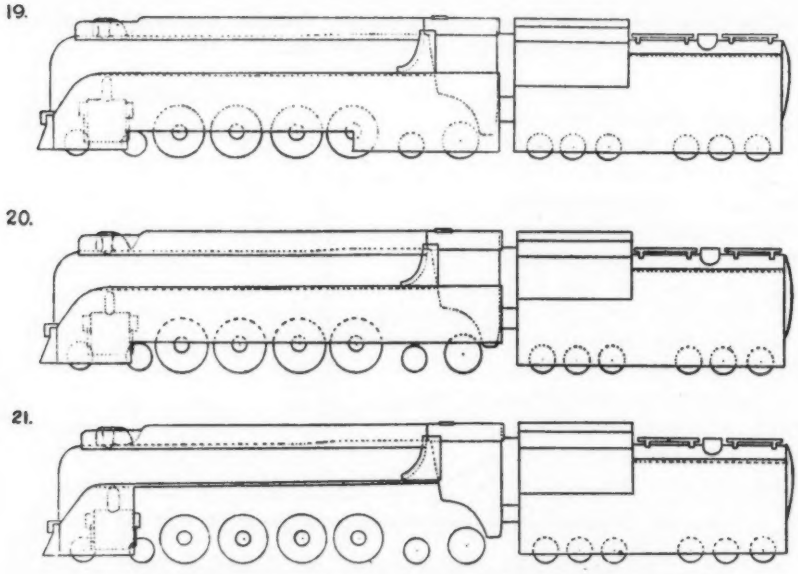


FIG. 15. *Drawings of model incorporating further modifications 19, 20, 21.*

the contribution of side curtains to the saving of resistance, this cutting down of their size was done in stages, the results being as follows:—

Full-size side curtains,

$$\frac{R}{V^2} \times 100 = 0.0633.$$

Side curtains cut off below the level of the centres of the driving wheels and from behind the cylinders to the centre of the rear driving wheels as shown in Fig. 15 (upper drawing),

$$\frac{R}{V^2} \times 100 = 0.0650.$$

(20) Side curtains cut away below level of driving wheel centres from the rear of the cylinders to the rear of the cab, as shown in middle drawing of Fig. 15,

$$\frac{R}{V^2} \times 100 = 0.0656.$$

(21) Side curtains removed completely from the rear of the cylinders to the rear of the cab as in lower drawing of Fig. 15,

$$\frac{R}{V^2} \times 100 = 0.0695.$$

(22) Side curtains cut away below the level of the top of the driving wheels from rear of cylinders to rear of cab, as in Fig. 16,

$$\frac{R}{V^2} \times 100 = 0.0702.$$

(23) Tender side curtains cut off below the level of the frame of the tender as shown in Fig. 16,

$$\frac{R}{V^2} \times 100 = 0.0715.$$

22.

23.

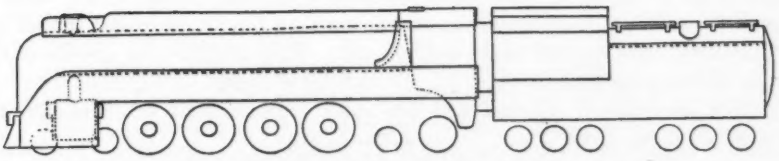


FIG. 16. *Drawing of model incorporating further modifications 22 and 23.*

(24) Side curtains completely removed from locomotive,

$$\frac{R}{V^2} \times 100 = 0.0846.$$

(25) Side curtains completely removed from locomotive and tender,

$$\frac{R}{V^2} \times 100 = 0.0865.$$

These results show how very vital side curtains are when the rest of the model is well streamlined, yet the addition of side curtains to the original otherwise unmodified model had practically no effect on resistance.

With present requirements regarding accessibility the arrangement shown in (22) was accepted as being possible to reproduce on full scale.

(26) *Final modifications to the front of the model.* In order to simplify the front of the locomotive and to induce the flow of large quantities of clean air from the front of the model over the top

26.

27.

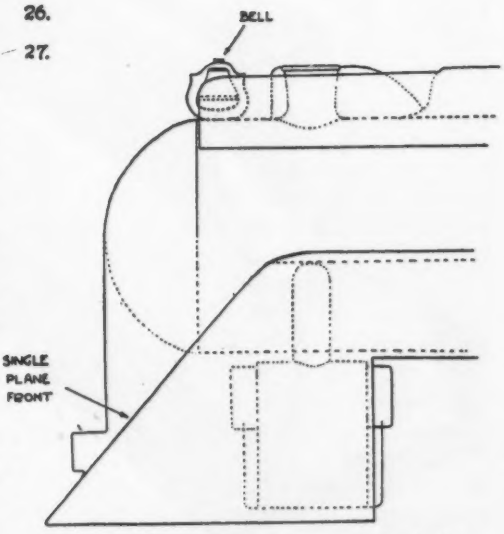


FIG. 17. *Drawing of model incorporating further modifications 26 and 27.*

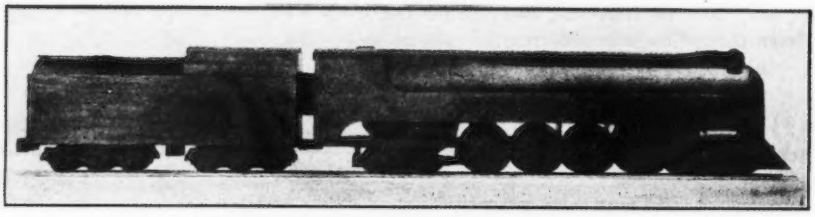


FIG. 18. *Model as finally modified, side view.*

and sides of the boiler, a sloping solid pilot running in one plane from as near the rail level as possible up to the running boards on either side of the boiler was fitted in place of the original one. This modification results in the style of front depicted in Figs. 18, 19 and the drawings of Fig. 17.

With this change effected and the model otherwise as in 23 above, the model drag was given by

$$\frac{R}{V^2} \times 100 = 0.0700.$$

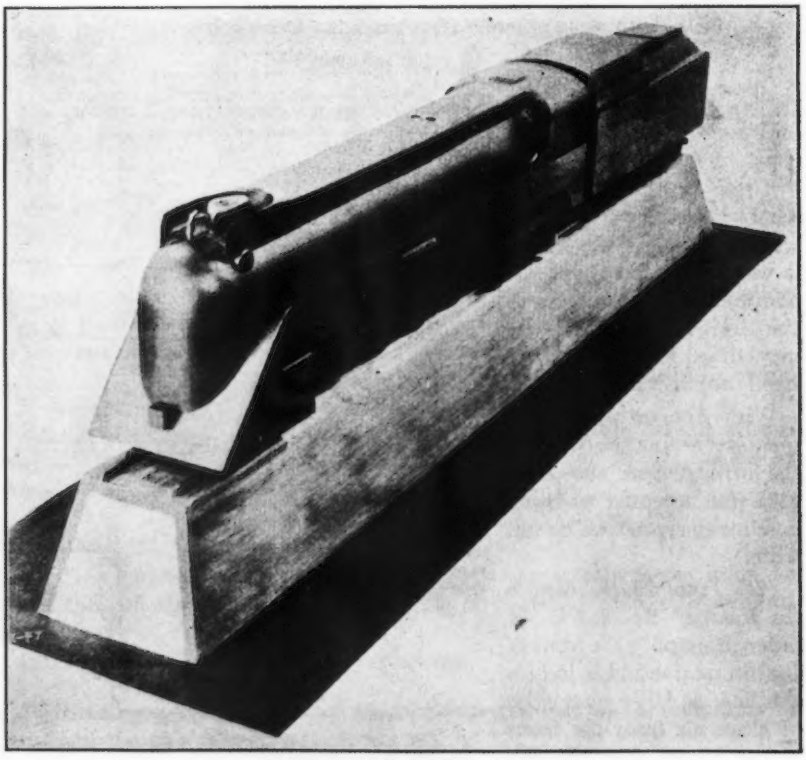


FIG. 19. *Model as finally modified, oblique view.*

(27) *Location of the bell.* The bell was originally placed on the side of the boiler but in this position it upsets the flow of air over the cab window. It was now placed in front of the stack (see Fig. 17) with its frame edgewise on to the wind and in this position it was found to have a shielding effect on the top of the stack, such that the flow in the region of the stack ascends much more rapidly than formerly, as shown in the photograph Fig. 20.

With the bell so located,

$$\frac{R}{V^2} \times 100 = 0.0706.$$

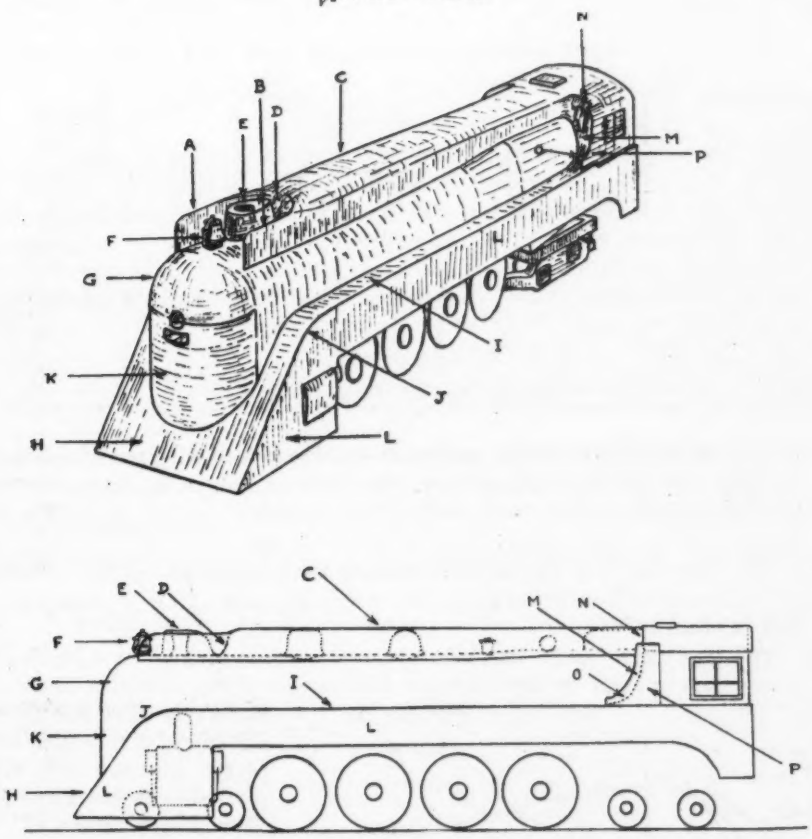


FIG. 21. *Drawings of completely modified model. A, B, side plates on each side of stack. C, cowling over the dome, turrets, etc.; A, B, are continuations of the sides of C. D, smooth curved surface from boiler top to top of cowling C. E, streamlined smoke stack. F, bell edgewise to the wind in front of the stack. G, approximately quarter spherical nose on boiler. H, inclined plane replacing pilot on existing types (coupler not shown in drawing). I, running boards. J, rounded front of running boards. K, Smooth cylindrical front between G and H. L, side curtains over cylinders, valve motion, etc. M, new front to cab — sloping backwards from the running boards. N, Smooth rounded corner between cab roof and new cab front M. O, smooth generous curve between running board I and cab front M. P, side plates fitted to cab sides and protruding somewhat forward of the cab front M.*

Conclusion

The model thus finally modified is shown in Figs. 18 and 19 and in the drawings of Fig. 21. It operates by inducing a layer of clean air under the smoke layer and by suitable cowling subsequently minimizes the intermingling of the smoke layer with the clean air layer. It introduces clean air along the boiler sides, which is ultimately swept upward in front of the cab windows.

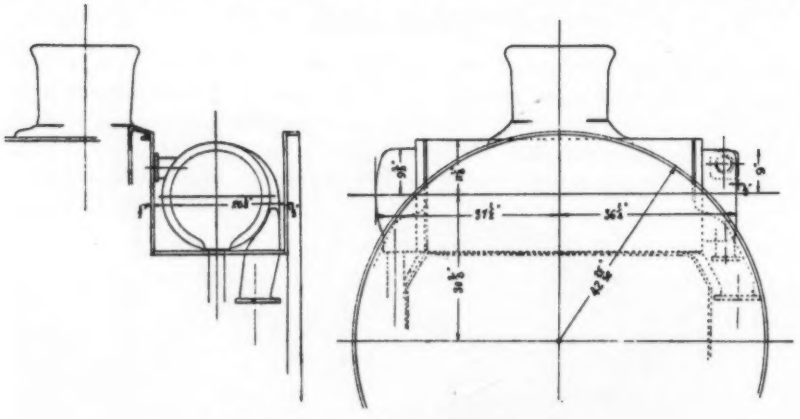


FIG. 22. *Location of feed-water heater.*

The modifications have been made with the idea of reducing turbulence and eddying and thereby cutting down the wind resistance as shown by the following results.

The value of $\frac{R}{V^2} \times 100$ has been reduced from 0.1089 to 0.0706, a reduction of some 35%.

The feed-water heater has been placed in a new position as a result of considerations made by the Operation Department of the Canadian National Railways. This position is just ahead of the stack and partly lowered into the smoke box as shown by Fig. 22, and Figs. 18 and 19.

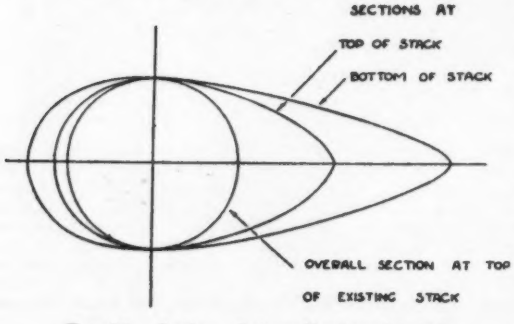


FIG. 23. *Sections of streamlined smoke stack.*

From the top surface of this feed-water heater, a level platform is taken back on either side of the stack and runs in a smooth curve into the cowling, over the dome and turrets.

Fig. 20 is a photograph of the silk streamers on the new model suspended in the tunnel with an air speed of 45 m.p.h. It forms an interesting contrast to the flow picture, Fig. 10, taken at the same speed with the original model.

The lifting of the smoke at the stack is clearly indicated by the streamers and the good flow over the top and sides of the boiler can be seen. The upward current of clean air over the cab window is also indicated.

Fig. 21 shows the developed model and indicates by letters the additions that must be made to existing types of locomotives to convert them to the improved type.

Application has been made for patents on the new design.

Acknowledgments

The author is grateful to Prof. J. H. Parkin, Assistant Director, Division of Physics, in charge of Aeronautics, for his assistance and valuable advice throughout the work and also to Mr. Brooks and Mr. Connal of the Operation Department of the Canadian National Railways, for their willing co-operation and the provision of photographs of a 6100 locomotive drifting, and a drawing showing the location of the feed-water heater which appear in this report.

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THE BREMIDAE OF MANITOBA[1]

By Ferris Neave[2]

Abstract

The distributional ranges of many species of Bremidae meet or overlap in Manitoba. The distribution of most of these species is shown to follow closely the summer isotherms, which, in general, run in a northwest to southeast direction. Three main areas are recognized, each characterized by the presence or absence of certain species: (1) southern, (2) central, (3) northern and eastern. In the latter, three sub-areas are indicated. In all, 23 species of Bremidae are recorded from the province.

When Franklin (1) published his indispensable work on the "Bombidae of the New World", six species of bumble bees were known from Manitoba. He indicated his belief that five others would be found in this region. The list, thus amplified, included nine species of *Bremus* (*Bombus*) and two species of *Psithyrus*. He comments (1, p. 198) on the apparent scarcity of species in Manitoba and certain other regions, adding, however, that "this may be due largely to lack of extensive collecting in these portions of Canada."

At the present time the writer has records of 23 species (19 *Bremus*, 4 *Psithyrus*) within this territory and other additions may be expected, particularly in the extreme north of the province. This is a larger number than is recorded by Franklin from any North American state or province lying wholly east of the Rocky Mountains, and though recent years have added species to many of these local lists the Manitoba total is very significant in view of the intensive collecting which has gone on in districts farther south and east. It is now evident that, far from showing a deficiency in these insects, Manitoba holds a key position in the distribution of many species, being the meeting ground on which various forms, whose centres of distribution lie farther north, south, east or west, find their natural limits. The province therefore has no characteristic "Manitoban" fauna of bumble bees, but is a forum for representatives from adjacent regions.

General Considerations

The geography of this part of Canada is well adapted to a distributional study of this kind. Owing to the comparative lack of vertical relief, the complicated local conditions which are introduced by peaks and ranges are eliminated and it is possible to observe the broad general effects of climatic influences. The Bremidae are favorable subjects inasmuch as they are large conspicuous insects, easy to find and to collect, and possess strong powers of flight which enable them to surmount small local barriers. As a result of this ability, combined with the physical nature of the country, there appear to be no "islands" in the distribution of the various species, though further collecting in the Riding Mountain district may well disprove this idea.

[1] *Manuscript received December 5, 1932.*
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The regional distribution of certain American bumble bees has been the subject of a paper by Lutz (4) who, however, approaches the subject from a phylogenetic viewpoint and indicates the range of the various species only in a very broad way. Published records were collected together by Lutz and Cockerell (5) in 1920, and many locality records have been published more recently by Frison in his numerous papers on the family. None of these articles increase our knowledge of the Manitoba forms except one of Frison's (3) which contains records of six species collected at Cormorant Lake, near The Pas, by J. Russell.

The present writer has had opportunities during the last seven years to collect bumble bees in many parts of the province, and, in view of the dearth of published information, he has relied very largely upon these collections in drawing up the present account. The localities at which collections have been made (by the writer or others) are indicated on the accompanying map (Fig. 1). At few of these points can it be claimed that exhaustive search has been made. In some cases only the casual picking up of a few specimens was possible. Nevertheless, even these incomplete records are of great assistance in forming a general picture of the distribution of the species. A glance at the map will show that the chief gaps are in the far north and northeast and to a less extent along the southern border.

Areas Recognized

On the basis of the data presented on later pages it is necessary to divide the province into at least three main areas, as indicated on the map. These areas may be defined briefly as follows:

I. A relatively small southern area characterized by the presence of *B. fervidus*, *B. nevadensis* and *B. separatus*.

II. A large central area comprising most of the settled parts of Manitoba. No species (except *B. huntii* which cannot be considered at all characteristic) is strictly confined to this area which, however, is sharply delimited by the absence of certain species belonging to the other two areas.

III. A northern and eastern area, which, as at present constituted, covers by far the greater part of the territory under discussion. Species characteristic of this area are: *B. couperi*, *B. melanopygus*, *B. mixtus*, *B. flavifrons*, *B. pleuralis*, *B. frigidus*, *B. sylvicola*, *B. kirbyellus* and *P. fernaldae*. The area, however, even at the present time can be divided into certain sub-areas. The writer is of the opinion that it will be necessary in the future to recognize a fourth main region in the north and northeast. *B. kirbyellus* may belong to this group, which will probably include also certain far-northern species not yet recorded from the province, such as *B. arcticus*, *B. polaris* and *B. strenuus*. At present we have no data to show where the boundary of this last area should be drawn.

The sub-areas can be diagnosed briefly:—

(A) A strip of country not more than 50 miles wide immediately adjacent to Area II and extending completely across the province. This zone is

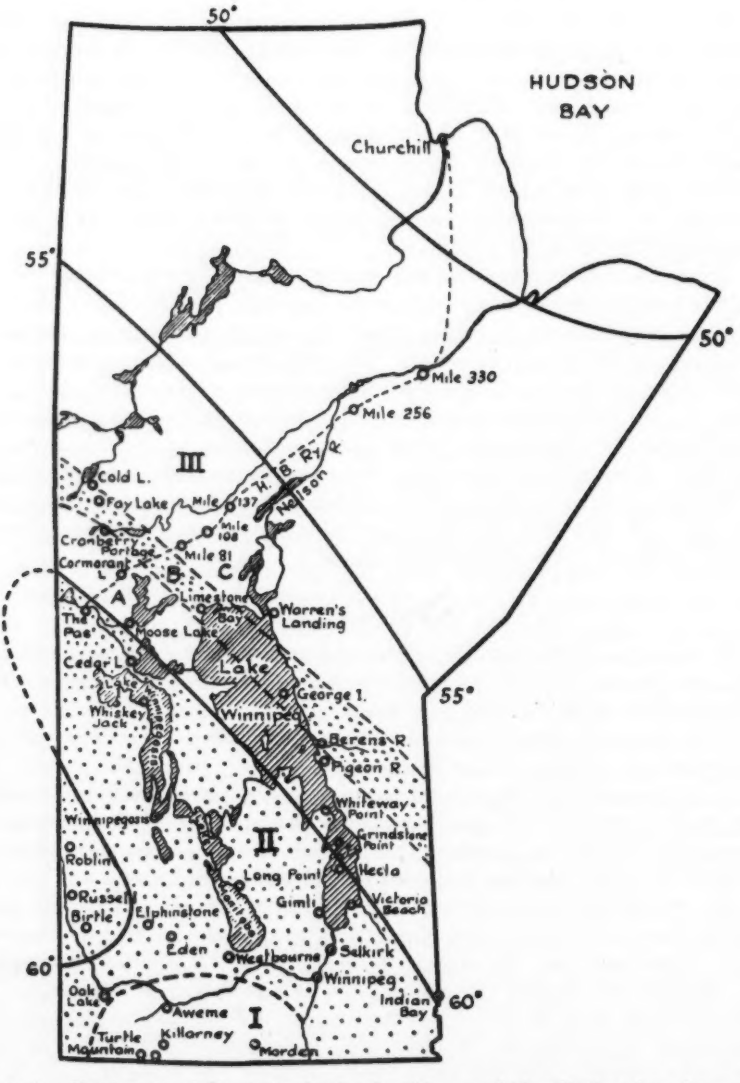

FIG. 1. *Sketch map of Manitoba showing localities at which collections have been made, summer isotherms and areas recognized in distribution of Bremidae.*

inhabited by *B. couperi* and *B. melanopygus*, but apparently not by the other species mentioned above.

(B) A similar narrow strip in which *B. mixtus* and *P. fernaldae* are present.

(C) Characterized by the presence of *B. pleuralis* and *B. frigidus*. The northeast boundary of this sub-area cannot be defined at the present time.

The numbers of species recorded at present from each main area are:—Area I, 9; Area II, 9; Area III, 17.

It is strikingly evident that the northeast part of the province is by far the richest in number of species, despite the fact that less collecting has been done in this area than in any other. It is obvious from these figures that many species are found in at least two of the areas. Nevertheless, only one species (*B. terricola*) occurs throughout the whole of the territory from which records are available. *P. ashtoni* is probably inquiline upon *B. terricola* and may be nearly co-extensive. *B. borealis*, *B. rufocinctus*, *B. ternarius* and *B. vagans* cover the whole of Areas I and II and range at least a little way into III, but are certainly not characteristic of the latter. *P. laboriosus*, which has been recorded as an inquiline upon *B. vagans*, probably has an equally wide distribution, though not yet reported from Area I. Some of the northern species also range over a vast territory, though this is not considered herein to represent more than one area. On the other hand, the species listed as characteristic of Area I have a very circumscribed distribution in the province, though a wide range outside it. *B. couperi*, again, is present (and quite common) in a narrow zone and, judging from published records, this may be true of its distribution in other parts of the country. A very similar altitudinal zoning of some of the same species is found in the Canadian Rockies (6). *B. borealis* and *B. ternarius* occur in the eastern foothills, while *B. kirbyellus*, *B. melanopygus*, *B. mixtus*, *B. sylvicola* and *P. fernaldae* occupy a high zone. There are, however, some minor differences. *B. terricola*, for example, appears to be somewhat more restricted in its vertical range than would be indicated by its horizontal distribution in Manitoba.

Factors Influencing Distribution

Doubtless there are various factors which play a part in controlling the distribution of these insects. Humidity, competition between species, and the character of the flora suggest themselves as probable influences. Temperature however appears to be the most obvious factor concerned. The accompanying map (Fig. 1) shows a striking correspondence between the geographical distribution of the species and the direction taken by the summer isotherms.* Further evidence of the importance of the temperature factor is obtained by considering the distribution of the various species outside the province. Of all the species listed here, it is probable that only one (*B. terricola*) can be considered to have its centre of distribution in or near Manitoba. The rest, or most of them, judging by published records, have their distributional centres at a considerable distance from this area. An examination of the available data shows that most of these centres lie either to the north and northwest or to the south and southeast. About 15 species can be located in these two directions. Only two species (*B. huntii* and *B. nevadensis*) can be classed as western and southwestern forms and it is doubtful whether any species represents invasion from the northeast. The explanation seems to be

* *Isotherms according to Atlas, Department of the Interior, Canada, 1906.*

that the distribution follows closely along the isotherms, which run in a northwest to southeast direction. Extension of range from southwest to northeast, or *vice versa*, would involve cutting across the isotherms.

Although the importance of temperature is thus readily to be seen, the question remains as to whether its effect is mainly a direct one, *i.e.*, exerted on the bees themselves, or an indirect influence working through modifications of the vegetation. The writer believes that the direct effect is considerable. This is indicated by differences in the length and texture of the hair between northern and southern forms. Further, the distributional limits of many species do not seem to coincide with any major changes in the type of vegetation,—in other words, these bees appear to be more sensitive than many of the plants. On the other hand, the boundary between Areas I and II does correspond very closely with the edge of the coniferous forests. Also, it may be noted that the slightly colder district in the western part of Area II shows no special Bremid features except perhaps in the presence of *B. huntii*. The vegetation in this district is similar, in its larger features, to adjoining parts of Area II. The flora, no doubt, is a strong factor in distribution and further work may show its importance in cases where its influence cannot be demonstrated at the present time.

Notes On The Species

In the following list, an asterisk denotes a new record for the province of Manitoba. Records which are not credited to any collector are due to the writer.

**Bremus separatus* Cress.

Confined to the southern part of the province. The only localities so far are Aweme (N. Criddle, also R. D. Bird) and Turtle Mountain. It may probably be found to occupy most of the area south of the Assiniboine valley and west of the Red River.

Bremus rufocinctus Cress.

Common throughout I and II and extending a little way into III. The most northerly records are Berens River in the east and Moose Lake in the west. The color variety *albertensis* Ckll. has an equally wide range.

**Bremus nevadensis* Cress.

This handsome species has been found only in the south of the province,—Aweme (R. D. Bird) and Turtle Mountain. Its occurrence here extends its known range in a northeasterly direction.

**Bremus fervidus* F.

Franklin (1, p. 392) says "almost certainly present in Manitoba", but its range within the province appears to be limited to about the same area as *B. separatus*; Aweme (N. Criddle, also R. D. Bird); Oak Lake (B. Sharman); Turtle Mountain.

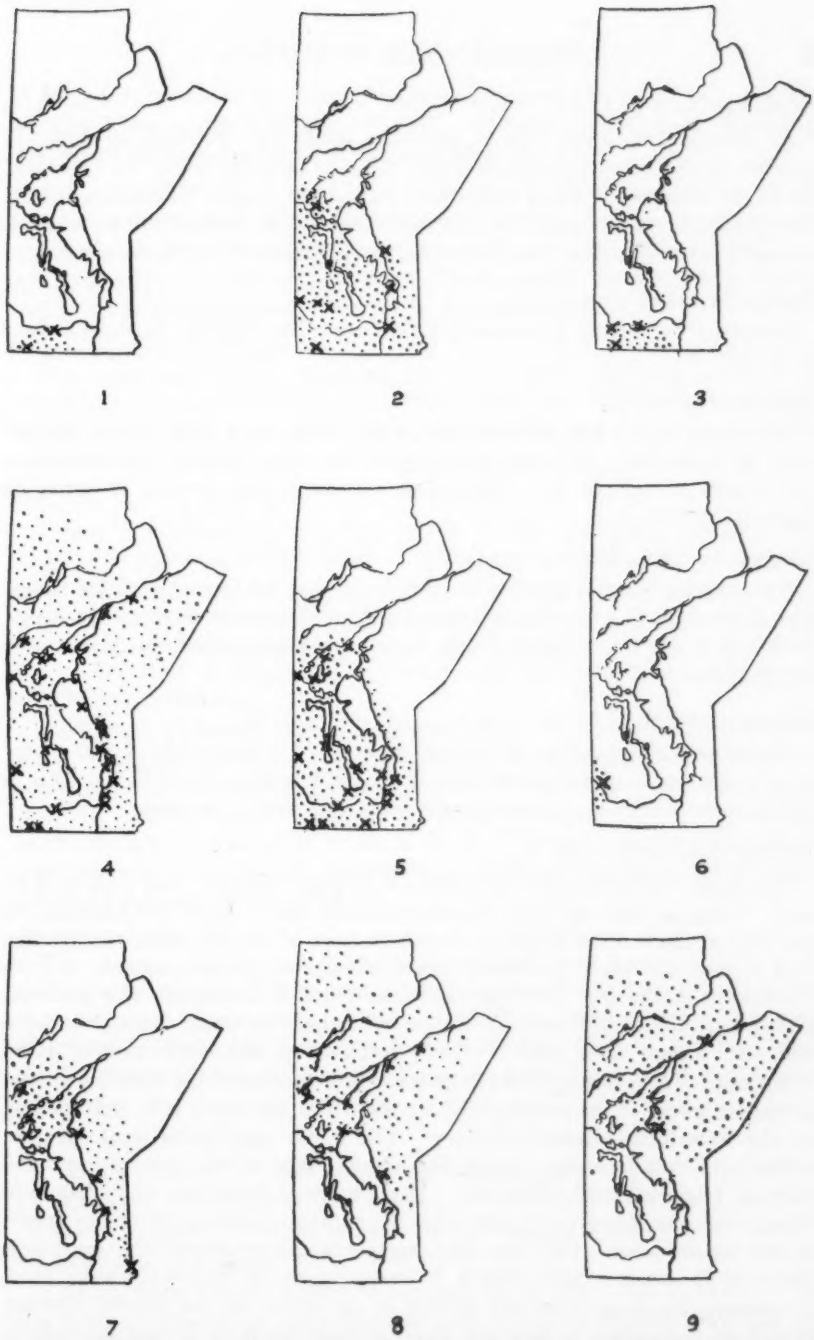

FIG. 2. *The crosses indicate actual locality records. The stippling indicates areas in which the species is expected to occur. In filling in the latter the known distribution of the species outside the province is taken into consideration. 1, B. nevadensis, B. separatus. 2, B. rufocinctus. 3, B. fervidus. 4, B. terricola. 5, B. ternarius. 6, B. huntii. 7, B. melanopygus. 8, B. mixtus. 9, B. frigidus.*

Bremus terricola K.

As already indicated, this is the most generally abundant species. It appears to be equally common from the southern boundary to the most northerly locality at which collections have been made (Mile 330, Hudson Bay Railway) and it probably extends considerably farther north, as it is recorded from "Hudson Bay Territory" and "Lat. 65° North America."

Bremus bifarius Cress.

Reported only from Cormorant Lake, near The Pas (J. Russell; Frison (3, p. 105).

Bremus ternarius Say

This is probably the commonest species throughout most of the settled parts of Manitoba. It is less plentiful in the north and east but extends as far as Mile 137, H. B. Ry. The queens do not appear so early in spring as those of *B. terricola*.

**Bremus huntii* Greene

This species reaches Manitoba at the extreme eastern edge of its range. The only record to date is a single queen taken at Birtle, 31.V.23 (R. D. Bird). It should be found at other points in the west of the province, but is probably not common.

**Bremus sylvicola* K.

Probably widespread in the far north of the province. The writer's only record is from Cold Lake, 90 miles north of The Pas, 9.VIII.31. This is the most southerly record for the species in this part of its range.

Bremus melanopygus Nyl.

The local distribution of this species is of great interest. Lutz (4, p. 515) says: "ranging from southern Alaska to Baffin Land, south to Colorado but not east of Saskatchewan in the southern part of its territory." It is true that it does not occur in southwestern Manitoba. Frison records it from Cormorant Lake, near The Pas (J. Russell) and it is undoubtedly common throughout northern Manitoba, as the writer has specimens from Cold Lake and also Moose Lake and Warren's Landing at the north end of Lake Winnipeg. From this territory it extends in a southeasterly direction to the southeast corner of the province, where the writer has taken it at Indian Bay, on the Manitoba-Ontario boundary. The writer also found it at Kenora, Ontario. These localities extend the known range of the species some 400 miles in a southeasterly direction. The southwest boundary of its range in Manitoba coincides very closely with the summer isotherm of 60° as represented on the map. This line also represents approximately the southwest limits of *B. couperi*, with which *B. melanopygus* is frequently associated. *B. couperi*, however, does not extend so far north as the present species. It will be interesting to find the distributional limits of *B. melanopygus* in Ontario and in northern Minnesota, where it should almost certainly occur.

It is frequently found on *Salix* in spring and appears to be an early species, at least in the southern part of its range. At Gull Harbor, Lake Winnipeg, the writer has taken workers as early as May 27.

**Bremus mixtus* Cress.

Another boreal form, which does not extend quite so far south as *melanopygus* but is characteristic of Area III–B and farther north. Southernmost records are Berens River and Limestone Bay. Further north, the writer has taken it at Fay Lake and at points on the H. B. Ry. between Mile 137 and Mile 327.

**Bremus frigidus* F. Smith

This form, which ranges from Alaska to Labrador, extends as far south as Warren's Landing at the north end of Lake Winnipeg. It has also been taken at Mile 330, H. B. Ry., indicating a wide distribution in the north of the province.

Bremus couperi Cress.

Frison (3, p. 114 *et seq.*) considers this form to be a variety of *frigidus*, with which it is "structurally identical." Without necessarily implying disagreement with this view, the present writer is keeping the two forms apart as a matter of convenience. In a distributional study they have to be treated separately, as their geographical ranges do not coincide, though they overlap to a small extent. In Manitoba, at any rate, the two forms appear to be always readily distinguishable.

As already indicated, *couperi* is absent from a large area in the south and west. It is particularly common along most of the shoreline of Lake Winnipeg and is plentiful even on small islands such as George Island, which is situated ten miles from the nearest mainland. It does not appear to range into the far north, though it occurs at Mile 108, H. B. Ry. The localities to date indicate a rather narrow range within the province. Both light-tailed and black-tailed forms are common in this zone.

Bremus perplexus Cress.

The range of this species is somewhat peculiar and does not seem to be determined by the same factors as most of the other Bremidae of the province. It is found, not very abundantly, over a fairly large area in eastern Manitoba. Winnipeg (J. B. Wallis, also F. N.); Gull Harbor; Victoria Beach; Berens River; Pigeon River. The species probably finds its northwestern limit in Manitoba.

Bremus vagans F. Smith

The distribution of this species corresponds very closely with that of *B. ternarius*. It is common over Areas I, II and III–A. The most northerly records are Pigeon River in the east and Cranberry Portage in the west.

**Bremus flavifrons* Cress.

This northern form is known so far only from Cold Lake, 9.VIII.31. It has been recorded from both east and west shores of Hudson Bay and will probably be found widely distributed in northern Manitoba.

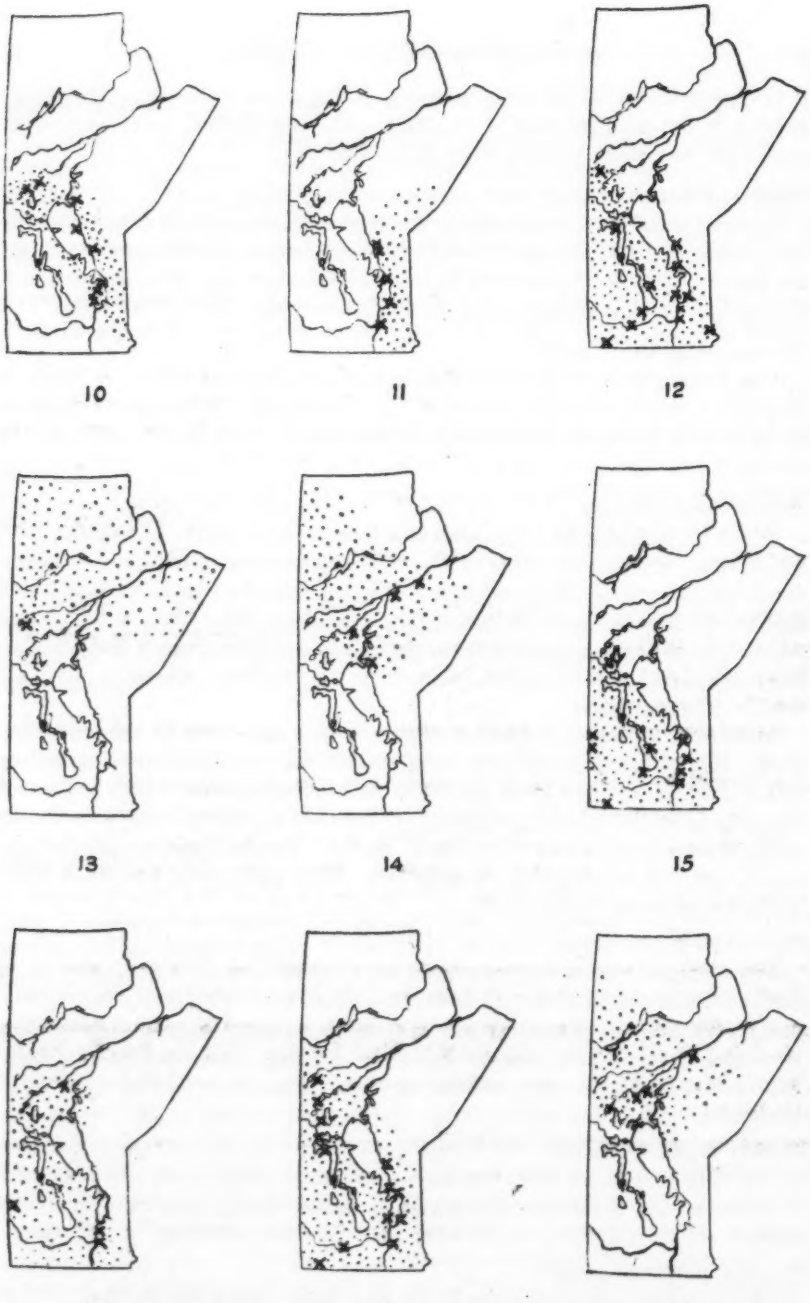

FIG. 3. *The crosses indicate actual locality records. The stippling indicates areas in which the species is expected to occur. In filling in the latter the known distribution of the species outside the province is taken into consideration. 10, B. couperi. 11, B. perplexus. 12, B. vagans. 13, B. flavifrons, B. sylvicola. 14, B. pleuralis. 15, B. borealis. 16, P. laboriosus. 17, P. ashtoni. 18, P. fernaldae.*

**Bremus pleuralis* Nyl.

Franklin records this species from Alaska only. More recently it has been reported from Yukon Territory, the mountains of Arizona, British Columbia and Fort Norman, west of Great Bear Lake. Its occurrence in northern Manitoba is therefore a very great extension of its known range*. Specimens collected by the writer, however, conform entirely to the specifications laid down for *pleuralis*, namely, a pure yellow band on the thorax and a sharply defined black inter-alar band. In addition, certain workers show the characteristic dark face. All are of the red variety which resembles *flavifrons* and *centralis*. The localities are: Warren's Landing; Mile 137, Mile 256 and Mile 330, H. B. Ry. These points indicate a wide zone of distribution.

**Bremus kirbyellus* Curt.

Nelson River, at junction of Butnau River, 1.IX.28, one male.

Bremus borealis K.

Though not very abundant, this species occurs throughout the whole of Areas I and II. The northernmost record is Moose Lake.

**Psithyrus laboriosus* F.

Not common but widely distributed; Winnipeg (J. B. Wallis, also F. N.); Selkirk; Russell; Mile 137, H. B. Ry.

Psithyrus insularis F. Smith

Cormorant Lake, 1.VII.27 (J. Russell), Frison (3).

Psithyrus ashtoni Cress.

Common throughout all the southern and central parts of the province. The writer's northernmost record is Cold Lake, but if, as is probable, this species is inquiline on *B. terricola* it may be expected much farther north than this.

Psithyrus fernaldae Franklin

Found so far only in northern Manitoba, though further collecting will probably extend its range in the east of the province. Frison records it from Cormorant Lake (J. Russell) and the writer has taken it at Limestone Bay and along the H. B. Ry., Mile 108 to Mile 260. Both in Manitoba and at Jasper, Alta., it appears to be associated with members of the subgenus *Pratobombus*.

Frison (2) recognizes nine subgenera in the North American species of Bremus, namely: *Fraternobombus* Skorikov, *Nevadensibombus* Skorikov, *Separatobombus* Frison, *Cullumanobombus* Vogt, *Alpinobombus* Kruger, *Terrestribombus* Vogt, *Pratobombus* Vogt, *Subterraneobombus* Vogt, *Fervidobombus* Skorikov. Also three subgenera of *Psithyrus: Laboriopsithyrus* Frison,

** It is interesting to note that Fort Norman, though 1200 miles away, has the same summer temperature as the more southerly Manitoban localities for the species.*

Ashtonipsithyrus Frison and *Fernaldaepsithyrus* Frison. While these groupings are not indicated in the foregoing treatment of the species, it may be mentioned that each of these subgenera except *Fraternobombus* is present in Manitoba. Very few of the political divisions of North America have a more representative fauna of bumble bees.

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DECOMPOSITION AND MOVEMENT OF HERBICIDES IN SOILS, AND EFFECTS ON SOIL MICROBIOLOGICAL ACTIVITY AND SUBSEQUENT CROP GROWTH[1]

By W. E. Bowser[2] and J. D. Newton[3]

Abstract

Experiments were conducted to determine the residual effect of sulphuric acid, copper sulphate, sodium chlorate, barium chlorate and sodium dichromate on three typical Alberta soils. No problem of residual effect was found with the two leaf sprays, sulphuric acid and copper sulphate. Sodium chlorate will remain toxic over a period of about two years, depending mainly on the organic matter content of the soil and the amount of leaching that takes place. The distance that the chlorate will leach down into the subsoil will depend on the amount of rainfall and the character of the soil. As soon as the chlorate is leached out or is reduced the soil returns to its normal productive power. Sodium dichromate decomposes very rapidly in the soil. It has a depressing effect on nitrification and on the activity of the soil micro-organisms. However, there is practically no residual effect from the use of sodium dichromate on soils of medium to high organic matter content.

Introduction

Ths use of chemicals for the destruction of weeds has made it necessary to determine the effects of these herbicides on subsequent crop growth. The effects will depend, in part at least, upon such factors as rate of movement of the herbicide in soils, rate of decomposition, and effect on soil microbiological activity. Thus, important soil problems have been created, and the purpose of this work was, therefore, to investigate the nature of the effect of weed herbicides on the soil.

Sulphuric acid, copper sulphate, sodium chlorate and sodium dichromate were investigated in relation to their effect on the soil processes and subsequent crops. A preliminary experiment with barium chlorate is also included. The chlorates and chromates act, at least in part, through the soil and results to date have definitely proved that a residual effect on the soil creates a problem.

In the experiments conducted three concentrations of pure chemical were used. These fairly well covered the range used for practical purposes. The concentrations are designated in this paper as Check, Concentration A, Concentration B and Concentration C. Table I shows the concentrations of the various chemicals used.

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TABLE I

RATES OF APPLICATIONS OF CHEMICALS TO SOIL REPRESENTED BY TREATMENTS A, B, C, ETC.

Check		A−		A		B		C		C+	
		Gm. per 100 gm.	Lb. per acre	Gm. per 100 gm.	Lb. per acre	Gm. per 100 gm.	Lb. per acre	Gm. per 100 gm.	Lb. per acre	Gm. per 100 gm.	Lb. per acre
H_2SO_4	None	—	—	.0024	30	.004	50	.008	100	—	—
$CuSO_4$	None	—	—	.0012	15	.0024	30	.0048	60	—	—
$NaClO_3$	None	—	—	.026	327	.052	654	.104	1308	—	—
$Na_2Cr_2O_7$	None	.013	163	.026	327	.052	654	.104	1308	.146	1838
$Ba(ClO_3)_2$	None	—	—	.039	489	.078	978	.156	1960	—	—

In most of the work three types of soil were used: Edmonton black, a rich black loam high in organic matter; Breton grey, a typical leached wooded soil; and Winterburn fine sandy loam, a soil of intermediate fertility. Duplicate crocks of these soils were used in all greenhouse experiments. The field experiments were conducted on plots in Belgravia field by permission of the Field Crops Department, University of Alberta. The plots were of even topography and of typical Edmonton black soil. The field had been fallowed the year previous to the beginning of the work. All field plots were in quadruplicate (see Fig. 1).

With the exception of two experiments all pot work was kept in a greenhouse at optimum moisture and cultivated at regular intervals. Two sets of experiments, one with sodium chlorate and one with sodium dichromate, to note their effect on microbiological activity, were kept at optimum moisture and maintained at one temperature in a laboratory control chamber.

In testing the residual effect on crop growth, wheat was the only plant used.

Methods

Chlorates

Chlorates were determined by the following method: the soil filtrate was boiled for 15 min. with standard ferrous sulphate and the excess titrated with standard potassium permanganate. This gave quite accurate results. The determination had to be carried out fairly quickly as the organic matter in the filtrate slowly reduced the potassium permanganate, and consequently reduced the chlorate readings. The first end-point reached was the correct one. This method is a modification of that of Treadwell and Hall (17, p. 398). It was the only one found satisfactory for such small amounts and applicable to the soil solution.

By adding flocculents it was found that a higher chlorate reading was obtained than by using a soil filtrate to which no precipitating agents had been added. This higher reading is undoubtedly due to less organic matter present in the filtrate.

It was found that the soils varied in the amount of chlorate recoverable. Using no precipitants, the following amounts of chlorate (expressed as percentage of chlorate added) could immediately be extracted by shaking for

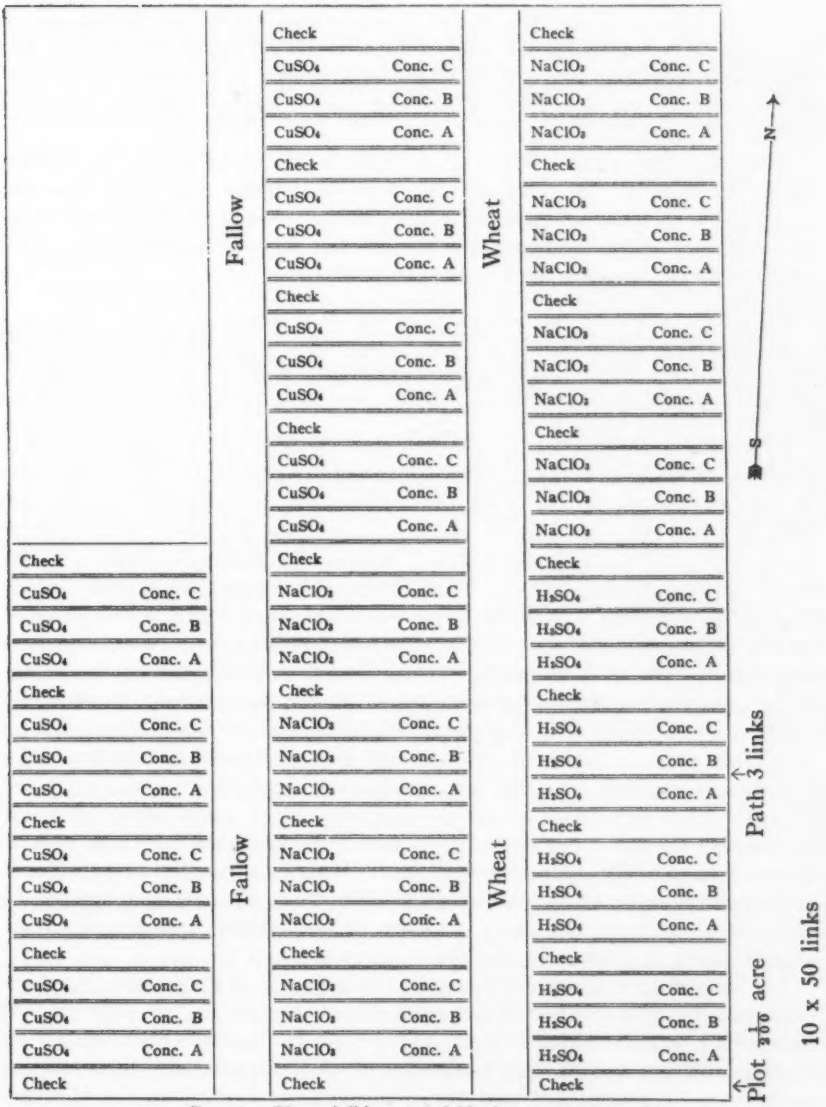

FIG. 1. *Plan of Edmonton field plot experiments with sulphuric acid, sodium chlorate and copper sulphate in 1931.*

one hour: from fine sandy loam, 80; from Edmonton black, 71; and from wooded grey soil, 90%. By adding copper sulphate, carbon black, magnesium carbonate and calcium hydroxide these values were increased to 90, 88 and 94%, respectively.

Dilute phosphoric acid was added to prevent action of the chloride ion on the potassium permanganate. Silver nitrate was added to the reduced and unreduced solutions, and the increased opalescence of the reduced samples showed that what was being measured was chlorates and not oxidation products of their decomposition.

The only other method found at all feasible was the silver nitrate method after reduction of the chlorate with ferrous sulphate, but even this was unsatisfactory. The amount of chloride was too small to weigh accurately and difficulty in the chromate titration method was encountered, due to the reaction of the reagents used in the reduction.

Nitrates

It was found impossible to determine nitrates in the presence of chlorate by Harper's (7) standard phenoldisulphonic acid method. The chlorate has an effect on the easily oxidized reagent, producing color tints that make an accurate reading impossible.

In most determinations the nitrates were in such minute quantities that titration of nitrates reduced to ammonia was impractical. The only satisfactory method that could be found for measuring the ammonia was Nesslerization. The difficulty was to measure accurately the small differences in soil nitrates due to the chlorate added. Scales' (16) method seemed to be the most satisfactory one to use. The procedure as developed is given below. A clear soil filtrate, one-tenth normal with sodium hydroxide was reduced with a zinc-copper couple. The distillate was treated with Nessler reagent and measured in Nessler tubes. It was found most satisfactory to obtain three different distillates; one where the alkaline solution was immediately reduced and distilled with the metal couple, one where the alkaline solution was boiled and distilled without the metal, and one where the boiled solution was then reduced and distilled with the metal couple. Since it was supposed that the differences found would be small, the object was to eliminate as far as possible the error due to free soil ammonia, ammonia from soil organic matter and the reduction of soil nitrates. Weighing the Nessler precipitate could not be expected to give accurate differences, but could sometimes be used as a check on the color readings. Considerable time was spent in standardizing and applying the above method.

For the determination of nitrates in the presence of chromates the phenoldisulphonic acid method was used. The chromate in the solution was reduced by ferrous sulphate, in the cold. The solution was then made very slightly alkaline and the precipitated iron salts filtered off. The solution could then be evaporated and the determination carried on by Harper's method. Care had to be exercised to prevent loss of nitrates by the vigorous reaction between the phenoldisulphonic acid and the excess of salts present.

Chromates

Chromates were determined by the potassium ferricyanide spot plate method as outlined by Treadwell and Hall (17, p. 548). The soil filtrate was titrated with standard ferrous sulphate using potassium ferricyanide as an outside indicator.

Micro-organisms

The numbers of bacteria and fungi were determined by the plate count method. A nutrient agar medium recommended by Fred and Waksman (5, p. 9, Medium 4) was used for the bacterial plates, and an acid agar medium recommended by Waksman (5, p. 13, Medium 18) for the fungi plates.

Experimental Results

Sulphuric Acid

Sulphuric acid is used as a leaf spray, generally for the control of annual weeds. Its lethal action is on the exposed part of the plant. Åslander (3) suggests that sulphuric acid does not move in the plant and its effect is dependent on the amount of surface the spray can cover. The applications recommended are from 30 to 100 lb. per acre. It is seen then that the amount of acid that reaches the soil is necessarily very small. One of the authors (15) found in Edmonton black soil that one ton of sulphur reduced the pH from 6.5 to 5.2 and in Breton grey podsolized soil from 6.7 to 5.1. This would suggest that the amount applied in the sulphuric acid experiments would have little or no residual effect on the soil.

A series of eight one-gallon crocks of each of the three following soils was placed in the greenhouse: Winterburn fine sandy loam, Edmonton black and Breton grey loam. Three different rates of application of sulphuric acid were used (see Table I), and all treatments and checks were in duplicate. A series of plots was laid out in the field in quadruplicate (see Fig. 1). These plots were treated with sulphuric acid on July 2, 1930. They remained fallow that year and were sown with wheat in 1931.

Nitrates and micro-organisms were determined periodically in the plots and crocks in 1930. The results were rather irregular but there appeared to be a very slight depression of the nitrates and fungi numbers late in the season in the field plots treated with sulphuric acid. By September 5 the nitrates on the check plots had increased from 30 to 36 p.p.m.,* while on the plots receiving Concentration C they had decreased from 28 to 21 p.p.m. However, it appears that there was no important detrimental effect on the soil biological activity as a result of the sulphuric acid application.

A crop of wheat sown in the crocks after six months showed no ill effect from the acid treatment. A slight stimulating effect due to the acid was noticeable in the poorer soils; *i.e.*, in the Winterburn fine sandy loam and the Breton grey.

The plots were sown with wheat the following spring, in May 1931. No apparent differences were seen in the growing crop. Threshed grain yields on the plots are given in Table II. No definite trend is noted and the differences in yield are not really significant.

p.p.m. = parts per million.

Copper Sulphate

As a result of the comparative success with copper sulphate as a chemical for the destruction of annual weeds it was decided in 1931 to test its residual effect. With copper sulphate, as with sulphuric acid, it was felt that the amount added was too small to have any detrimental residual effect on the soil. Bourcart (4) says, "The soil is capable of absorbing enormous quantities of copper sulphate without the latter injuring the plant". He also suggests that this is due to the formation of the more insoluble and less toxic copper salts by reaction with the soil. This is emphasized by Marshall (12, p. 292) who points out that with metallic salts the toxic action will depend mainly on the metal in solution. A series of 24 crocks similar to that used for the sulphuric acid treatment was placed in the greenhouse. The treatments were as stated in Table I. The crocks were maintained in the greenhouse at optimum moisture and cultivated every two weeks.

Nitrates were determined monthly for four months by the phenoldisulphonic acid method (see Table III). Although no definite trend can be noted it appears as if there was some stimulation in the richer soils due to the copper sulphate. This stimulation lasted only a short time after application. It also appears as if the weakest concentration stimulated sooner than the next higher concentration. Greaves' (6) work on the effect of salts on soil micro-organisms shows that a stimulation can be expected in weaker concentrations of a toxic salt. This is what appears to have happened with the addition of copper sulphate in small amounts.

TABLE II

WHEAT YIELDS OF EDMONTON FIELD PLOTS 1931; STRAW IN TONS PER ACRE, WHEAT IN BU. PER ACRE

Treatment		Date of application		
		July, 1930	June, 1931	July, 1930
		H_2SO_4	$CuSO_4$	$NaClO_3$
Ch.	Straw	3.95	4.06	3.88
	Grain	55.3	51.9	50.1
	% Grain	33.8	31.2	31.8
A	Straw	3.63	4.29	.88
	Grain	50.5	57.3	7.3
	% Grain	33.7	33.1	19.3
B	Straw	3.37	4.04	.51
	Grain	45.3	56.9	1.7
	% Grain	32.8	34.3	7.8
C	Straw	3.55	3.70	.17
	Grain	50.5	52.3	.02
	% Grain	34.6	34.7	1.2

NOTE: *The sulphuric acid applied in 1930 and the copper sulphate applied in 1931 had little effect on the 1931 wheat yields, but the sodium chlorate applied in 1930 had a very great effect on 1931 wheat yields.*

See Table I for rates of application represented by Treatments A, B, and C. Each yield figure represents an average of four plots.

TABLE III

NITRATES (P.P.M.) IN POT CULTURES TREATED WITH COPPER SULPHATE, 1931

	March 3	May 9	June 6	June 30	Aug. 14
Wooded Ch.	Trace	36	31	27	40
" A	"	32	46	29	36
" B	"	33	35.5	27	24
" C	"	35	26	37	23.5
Fine Sandy Loam Ch.	7.2	44	64	57	36
" " A	7.2	48.5	70	39	73
" " B	7.2	42	100	44	57
" " C	7.2	38	35	40	133
E. Black Ch.	24	50	70	99	182
A	24	61.5	80	100	160
B	24	70	94	88	159
C	24	52	67	100	133

NOTE: *The nitrates show no definite trend following the application of copper sulphate.*

Six months after treatment with the sulphate the crocks were sown with wheat. No difference was noted in germination or in subsequent growth.

On June 26, copper sulphate was applied to a series of plots of growing wheat. There was a heavy rain 12 hr. after application. Two days later considerable burning of the wheat leaves was observed. The plots receiving 60 lb. per acre appeared quite brown. As the wheat neared maturity the check plots lodged badly, while those receiving sulphate remained upright. The yields of wheat on these plots are given in Table II.

These figures show a small but definite increase in the ratio of grain to straw with the application of copper sulphate. A stimulation due to Concentration A and a depression due to Concentration C might also be noted. However, neither one of these is significant. If the check plots had not lodged they would, probably, have given a significantly higher yield than the treated plots.

A series of fallow plots was treated on June 26, 1931. The copper sulphate had a lethal effect on the growing weeds at the time of application. However, it did not have any apparent residual effect on any growth appearing after its application.

Sodium Chlorate

Chlorates are used mainly for the eradication of perennial weeds because their toxic action appears to persist over a much greater period of time than that of the leaf sprays, and chlorates therefore present the greater residual effect problem. Sodium chlorate was used as the type example and the major part of this work was devoted to its study.

The experiments conducted have shown that sodium chlorate affects certain normal soil processes to a limited extent. It has not been possible, however, from this investigation to explain why it acts in this manner.

Up to the present there are no definite data as to the cause of toxic action of chlorates*. Neller (14) says it is possible that the slower action and the higher toxicity of sodium chlorate are due to its gradual decomposition within the plant tissues, accompanied by the liberation of nascent oxygen. Neller also suggests that the chlorates lower the catalase activity of the roots. Loomis, Bissey and Smith (11) believe that the herbicidal action consists of both direct killing of underground portions of the plant and of a translocation to, and slow killing of, new sprouts. Latshaw and Zahnley (10) suggest that it interferes with photosynthesis and compels the plant to draw upon the root reserves until they are exhaused and die. However, Loomis, Bissey and Smith (11) say its action can go on in the absence of ultra-violet light. Although our results show that the chlorate has a definite effect on microbiological processes in the soil it appears quite evident that its toxic action is not from that source. Loomis, Bissey and Smith (11) and Åslander (2) suggest that the chlorate is more effective if applied to the soil. It seemed reasonable, therefore, to suggest that a study of its effect on the soil and its movement in the soil is important.

FIG. 2. *Wheat on field plots the year following treatment with sodium chlorate.*

A series of plots in quadruplicate was laid out in the spring of 1930. These were treated July 28, 1930, with sodium chlorate according to Table I. Bacteria and fungi determinations were made at intervals during the year. The numbers are rather irregular and show no definite trend following the application of chlorates. Nitrates were not determined that summer, as no satisfactory method of determining nitrates in the presence of chlorates was at that time standardized.

In the spring of 1931 the plots were sown with wheat. Chlorate damage was noticed with the first appearance of the shoots. The plots receiving the heaviest application were practically barren. What few seeds germinated or appeared above the surface survived only a short time. Any growth supported by these plots, Concentration C, germinated almost a month later. Fig. 2 shows the appearance of the plots shortly before harvest. The yields of wheat are shown in Table II and indicate the graded or corresponding effects of the different concentrations applied. All applications of chlorates materially

* *The writers have been unable to find any published article that deals directly with the effect of the oxidizing chemicals on the soil.*

reduced the yield. The plot receiving Concentration A, 327 lb. per acre, gave a yield of 7 bu. per acre as against a 50-bu. yield on the check plot. Concentration B and Concentration C reduced the yield to practically nothing. Concentration B, 654 lb. per acre, approximates the average application recommended for the control of perennial weeds. It appears that under climatic conditions such as prevailed in 1930, Edmonton black soil, treated with 600 lb. of sodium chlorate per acre, will inhibit the growth of wheat for at least one year. The 1930 season was relatively dry with a long open dry fall. Although no analyses were made it may be supposed that in the spring of 1931 the chlorate was still concentrated quite close to the surface. It was, therefore, quite toxic to the young plants. These results are similar to the findings of Arny, Bridgford and Dunham (1). They state that when from 600 to 800 lb. per acre were applied the soil often remained sterile for a year. Megee and Lipscomb (13) state that the residual effect of a spring application usually disappeared by September. The length of time that chlorates will remain in the soil, toxic to the plant, seems to be a point upon which many different opinions are expressed. The investigations indicate that although the fertility of the soil and its percentage of organic matter are factors, rainfall and leaching are more important because they affect its distribution in the soil and therefore its toxicity to the plant.

On August 18, 1931, the upper three feet of soil were sampled and analyzed for chlorate content, each foot separately. It was found that most of what still remained undecomposed was concentrated in the third foot (see Table V). The season of 1931 was one of high rainfall. This possibly explains why growth starting on the plots later in the season appeared almost normal. The questions raised by these analyses are whether the chlorate will decompose as rapidly in the subsoil, and whether excessive evaporation later will bring it back close to the surface.

These plots were planted with wheat in 1932. All the plots germinated well and for the first part of the season no effect of the chlorate could be noticed. By August 1 some of the lower leaves were browned on Plot C. It appeared that there might be a slight reduction in yield on this plot. Plots A and B showed no apparent effect. This would indicate that not all of the chlorate has decomposed in the two years; but that it has leached quite far down into the subsoil.

A field series similar to the one above was treated with sodium chlorate in June 1931. Analysis for chlorate content made in August 1931 (see Table V) indicated a rapid leaching into the subsoil. In 1932 this series was divided lengthwise into four strips. The strips were sown with wheat, oats, barley, and flax, respectively. This was planned as a preliminary experiment to see if there was any difference in the resistance of various crops to chlorate toxicity. The yields are shown in Table IV.

The difference between check and Concentration C in the wheat strip is much less than the difference noted between similar concentrations the previous year. This is undoubtedly due to a greater rainfall and therefore a greater amount of leaching. The wheat and oat yields were each reduced

TABLE IV

YIELD OF GRAINS, 1932, ON PLOTS TREATED THE PREVIOUS YEAR WITH SODIUM CHLORATE

Crop	Concentration	Yield, per acre		Crop	Concentration	Yield, per acre	
		Grain, bu.	Straw, lb.			Grain, bu.	Straw, lb.
Wheat	Check	43.3	4850	Barley	Check	72.0	5728
	A	39.6	4330		A	30.6	3160
	B	25.2	2925		B	19.7	2208
	C	23.2	2497		C	10.4	1136
Oats	Check	104.5	6362	Flax	Check	6.1	5186
	A	90.9	4588		A	13.4	3724
	B	84.4	4257		B	13.4	3368
	C	62.3	3347		C	13.3	2464

about 40% by Concentration C of chlorate. The barley seemed least resistant, the yield being reduced about 85% by Concentration C of chlorate. The flax yield was not reduced. The increased yield of the treated plots over the check plot is due to weeds and volunteer grain being killed by the chlorate. It would appear that the chlorate had leached beyond reach of the more shallow-rooted flax plant.

Loomis, Bissey and Smith (11) state that chlorates are leached in the soil and under moist conditions become concentrated in the lower levels of the soil. This they say is next only to temperature in importance. Our investigations suggest that ordinary temperatures have little effect on the decomposition of sodium chlorate. Greenhouse temperature for 18 months has failed to decompose it completely in the soil. The following experiment suggests that the chlorate does not enter into chemical union with the soil, and that once leached out, the soil returns to its normal productive power.

On October 27, 1931, samples of the upper three feet were again taken (and analyzed for chlorate content). Portions of these samples were placed in tumblers in the greenhouse and seeded to wheat. Growth relations at the end of five weeks are shown in Table VI. This experiment indicates that the chlorate can be leached out beyond the limit of its toxic concentration and that a normal growth can be subsequently supported. Hulbert, Remsberg and Spence (9) state that cultivating the treated soil, before the following spring, renders the chlorate less effective. This, it is suggested, is related to the leaching factor. The surface soil can be leached of its chlorate beyond the limit of its toxic concentration. Cultivation would therefore permit the upper broken portions of the roots to produce healthy plants, away from the action of the chemical.

A series of three soils was placed in the greenhouse in 1930 and treated with sodium chlorate at the rates stated in Table I. The soils and the arrangement of crocks were the same as in the case of the sulphuric acid experiment previously discussed. The soils were maintained at optimum moisture and

cultivated every two weeks. Fungal and bacterial counts showed no definite trend. This was partly due to the fact that neither the temperature nor humidity could be controlled. An experiment discussed later, conducted in

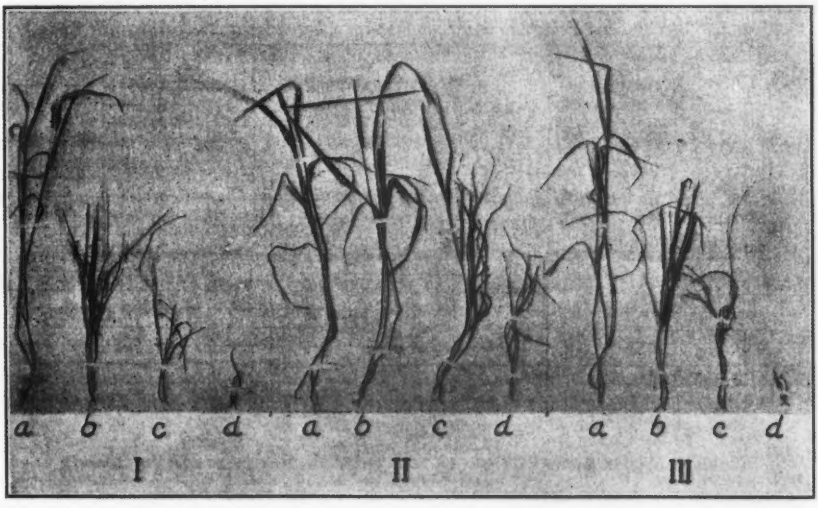

FIG. 3. *Growth of wheat on soil maintained under greenhouse conditions six months after application of sodium chlorate. I, Breton wooded soil. II, Edmonton black soil. III, Winterburn fine sandy loam. a, check; b, ¾ lb. per 100 sq. ft.; c, 1½ lb. per 100 sq. ft.; d, 3 lb. per 100 sq. ft.*

TABLE V

PENETRATION OF SODIUM CHLORATE IN THE EDMONTON SOIL UNDER FIELD CONDITIONS. DETERMINATION MADE AUGUST 18, 1931

Concentration	Depth in feet	Applied July, 1930		Applied June, 1931		Amount added per plot
		Gm. per plot	Total per plot	Gm. per plot	Total per plot	
Check	0 to 1	0.0		0.0		
Check	1 to 2	0.0		0.0		
Check	2 to 3	0.02		0.02		
			.02		.02	None
Conc. A.	0 to 1	0.0		0.0		
Conc. A.	1 to 2	123.0		82.0		
Conc. A.	2 to 3	240.0		369.0		
			363.0		451.0	742.0
Conc. B.	0 to 1	0.0		0.0		
Conc. B.	1 to 2	123.0		246.0		
Conc. B.	2 to 3	410.0		492.0		
			533.0		738.0	1483.0
Conc. C.	0 to 1	123.0		164.0		
Conc. C.	1 to 2	410.0		574.0		
Conc. C.	2 to 3	574.0		738.0		
			1107.0		1476.0	2966.0

NOTE: *These determinations indicate that the sodium chlorate tends to leach down into the subsoil in a moist season.*

TABLE VI

CROP (5 WEEKS GROWTH) ON FIELD SAMPLES TAKEN OCTOBER 27, 1931, FROM EDMONTON PLOTS PREVIOUSLY TREATED WITH SODIUM CHLORATE

Treated July	0–1 Foot	1–2 Feet	2–3 Feet
1930 Ch.	Normal growth	Normal growth	Normal growth
A	Normal growth	Normal growth	Normal growth
B	Normal growth	Normal growth	Some whitening
C	Normal growth	Some whitening, ¾ crop	Some whitening and retardation, ½ crop
1931 Ch.	Normal growth	Normal growth	Normal growth
A	Normal growth	Some retardation, ¾ crop	Some retardation, ¾ crop
B	Normal growth	Some whitening, ¼ crop	Some retardation and whitening of leaves, ⅓ crop
C	Some leaves dead, ¾ crop	Some whitening and retarding of crop, ½ crop	Whitened and retarded, ⅓ crop

NOTE: *These results indicate that the sodium chlorate will leach down into the subsoil in a moist season. A normal growth is supported once the chlorate is leached out.*

TABLE VII

SODIUM CHLORATE DECOMPOSITION IN POT CULTURES; GRAMS OF SODIUM CHLORATE PER 100 GM. OF SOIL

Soil	Series II	Series I	
	August, 1931	September, 1931	December, 1931
Black Ch.	—	—	—
Black A	.005	.001	—
Black B	.029	.019	.011
Black C	.080	.049	.051
F.S.L. Ch.	—	—	—
F.S.L. A	.005	.004	.006
F.S.L. B	.031	.010	.012
F.S.L. C	.050	.051	.040
Wooded Ch.	—	—	—
Wooded A	.016	.008	.011
Wooded B	.042	.020	.027
Wooded C	.086	.046	.036

NOTE: *Series I was started in July 1930 in the greenhouse and maintained at optimum moisture throughout.*

Series II was started in November 1930. It was left outside frozen till spring and then placed under greenhouse conditions in May 1931.

This table shows the more rapid decomposition of sodium chlorate under greenhouse conditions.

a controlled chamber, gave more significant results. At the end of six months the crocks were sown with wheat. The appearance of the crop is shown in Fig. 3. The heaviest concentration on the Breton grey soil practically prevented any growth whatever. Crops sown at 9 and 12 months showed a slight but steady improvement, especially in the Edmonton black soil. At the end of 12 months all the black-soil crocks were practically back to

normal excepting the C Concentration, which showed about a two-third's crop. At the end of the 12 months' period the C Concentration on the Breton grey still gave a 100% retardation of growth.

Table VII shows the amount of chlorates remaining in the soil. It shows that decomposition is taking place very slowly in the two poorer soils, and that in the richer black soil under greenhouse conditions it will take at least a year for 650 lb. per acre to decompose.

One year after the application of the chlorate one of each of the duplicates of this series was leached with six inches of tap water. The amounts of sodium chlorate obtained by this leaching are shown in Table VIII. The results indicate that it is possible to leach most of the chlorate out, but that it is more difficult to leach it out of the richer soils.

One month after these crocks were leached they were planted with wheat. As compared with the unleached crocks of the series, the leaching had removed much of the toxic element. However, the leached crocks all show some chlorate damage. In three weeks Concentration C wooded leached had a crop 3 in. high, whereas the wheat on the unleached did not appear through the surface (see Fig. 4).

There was practically no difference between Concentration C black soil leached and unleached. It was thought that possibly the chlorate might have left a toxic oxidation product in the soil of high organic matter content, but later experiments seem to disprove this. As suggested before, the chlorate is harder to leach out or extract from the richer soils. This suggests that chlorates remain relatively free in the soil and that they can be moved about in the soil by soil water.

A series of 24 crocks treated with chlorate was started November 10, 1930, and left outside, buried at ground level all winter. The frost did not appear to have any beneficial effect in aiding decomposition. Amounts of chlorate in this series are given in Table VII.

An experiment was outlined to test the neutralizing effect, if any, on chlorate, of farmyard manure, sulphuric acid and sulphur. Sixteen crocks of fine sandy loam were placed in the greenhouse. There were four each of (1) manure, 25 tons per acre; (2) sulphur, one ton per acre; (3) sulphuric acid, one ton per acre; and (4) four check crocks. Two crocks of each set were treated with sodium chlorate at the rate of 654 lb. per acre. They were kept fallow for six months, and at the end of this time a crop of wheat was planted. In general none of these satisfactorily neutralized the toxic effect of the chlorate. All samples treated with chlorate showed much

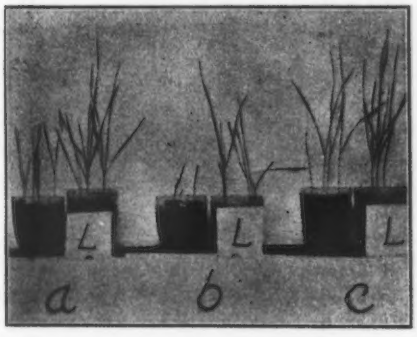

FIG. 4. *The effect of leaching soil one year after treatment with sodium chlorate. Tumblers marked "L" were leached with six inches of water. a, fine sandy loam; b, wooded; c, black.*

damage. There was no advantage whatever noted for the sulphur over the check. The sulphuric acid appeared slightly better than the check. The crocks treated with manure supported a growth twice as great as that of the check crocks, but it was badly whitened and of a spindly nature.

TABLE VIII

LEACHING OF CROCKS ONE YEAR AFTER TREATMENT WITH SODIUM CHLORATE. FIGURES REPRESENT GRAMS OF SODIUM CHLORATE PER 3000 GM. OF SOIL

	First 2-in. leachings	Second 2-in. leachings	Third 2-in. leachings	Total 6 in. from 3000 gm.	Amount remaining after leaching	Amount decomposed in one year	Amount applied
Wooded grey Ch.	.013	.006	.004	.023	.013	−.039	0.0
Wooded grey A	.469	.064	.022	.555	.053	.211	.78
Wooded grey B	.865	.186	.103	1.154	.079	.366	1.56
Wooded grey C	2.165	.386	.144	2.695	.106	.368	3.13
Fine Sandy Loam Ch.	.009	.007	.006	.022	.053	−.075	0.0
Fine Sandy Loam A	.525	.041	.034	.600	.053	.202	.78
Fine Sandy Loam B	.609	.148	.093	.850	.095	.690	1.56
Fine Sandy Loam C	1.000	.428	.137	1.565	.095	1.545	3.13
Edmonton Black Ch.	.009	.003	.003	.015	.039	−.054	0.0
Edmonton Black A	.463	.012	.007	.482	.039	.310	.78
Edmonton Black B	.542	.100	.048	.690	.119	.722	1.56
Edmonton Black C	1.173	.327	.180	1.680	.265	1.236	3.13

NOTE: *The results indicate that it is possible to leach most of the chlorate out of soils, but that it is more difficult to leach it out of the richer soils. The quantities in the check samples represent the error of the determination, and allowance is made for this error in the column of amounts decomposed in one year.*

The amounts of chlorates were determined after the crop was removed. Very little difference was noted in the results, although slightly more had decomposed under manure than in the other three, namely, sulphur, sulphuric acid and check crocks.

The above experiment suggested that if sufficient organic matter were added to the soil the effect of the chlorate could be neutralized. Further, that if an excess of easily decomposed alfalfa were added to the soil more definite information could be obtained as to the effect of sodium chlorate on nitrates and nitrification processes.

Three series of four jars each were prepared and treated with chlorate, at the same rates as in previous experiments. Series I was fine sandy loam alone, Series II was fine sandy loam plus 5% of alfalfa, and Series III was fine sandy loam plus 10% of alfalfa. Two weeks after application of the chlorate excessive decomposition was noted in Series III. The extent of decomposition was apparently proportional to the chlorate added.

Analyses for chlorate are given in Table IX. Where 10% of alfalfa was added practically all of the chlorate was decomposed within four weeks. In six weeks wheat was sown on a portion taken from each jar. Series I showed the expected harm from the chlorate. Series II showed a little effect of the chlorate and Concentration C supported about half a crop. In

TABLE IX

DECOMPOSITION OF SODIUM CHLORATE WITH EXCESS ORGANIC MATTER IN SOIL POT CULTURES; SODIUM CHLORATE IN GM. PER 100 GM. SOIL

		Added	4 Weeks	6 Weeks	8 Weeks	10 Weeks	14 Weeks
	Ch.	None	—	—	—	—	—
Series I	A	.026	.026	.014	.025	.019	.002
Fine sandy loam	B	.052	.037	.028	.037	.034	.033
	C	.104	.097	.083	.075	.080	.078
	Ch.	None	—	—	—	—	—
Series II	A	.026	.021	.012	.013	.011	.008
F.S.L. + 5% of alfalfa	B	.052	.037	.032	.023	.024	.031
	C	.104	.086	.067	.075	.070	.081
	Ch.	None	—	—	—	—	—
Series III	A	.026	.011	.010	—	—	—
F.S.L. + 10% of alfalfa	B	.052	.012	.011	.010	—	—
	C	.104	.006	.003	.009	.005	—

NOTE: *These results indicate that sodium chlorate will decompose quite rapidly in a moist well-aerated soil, in the presence of 10% readily decomposable organic matter.*

Series III a normal healthy crop grew on all four jars. There was no evidence of any residual effect from any of the concentrations. This suggests two conclusions: first, that it is possible to add enough organic matter to decompose the chlorate, and second, that when it has decomposed it does not leave any lethal oxidation products, and that the lethal substance is definitely the chlorate itself (see Fig. 5). This does not bear out Harper's (8) conclusion that chlorates disappear quickly from the soil in a warm moist climate and that their toxic effect is due to the depression of nitrating power or to the residual oxidation products of chlorate decomposition.

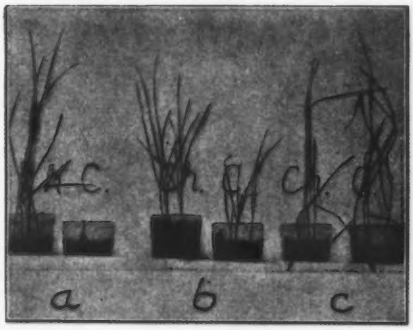

FIG. 5. *The neutralizing effect of ground alfalfa added to sodium chlorate treated soil. Wheat was sown ten weeks after the chemical was applied. a, fine sandy loam alone; b, fine sandy loam plus 5% alfalfa; c, fine sandy loam plus 10% alfalfa.*

Nitrates were determined on the three series at intervals. Results are given in Table X.

On fine sandy loam without the addition of alfalfa, there was, if anything, a stimulation of nitrification up to six weeks due to the chlorate application. By eight weeks that difference was levelling out and by ten weeks a noticeable retarding of nitrate accumulation was noted. In Series II with 5% of alfalfa added a reverse effect was noted. After four weeks there was a rapid increase of nitrate in direct proportion to the chlorate added. This series is significant

TABLE X

NITRATE NITROGEN (P.P.M.) IN FINE SANDY LOAM POT CULTURES TREATED WITH CHLORATE AND ALFALFA SEPT. 3, 1931

		2 Weeks	4 Weeks	6 Weeks	8 Weeks	10 Weeks	14 Weeks
Series I	Ch.	12	15	10	13	62	41
	A	12	15	10	22	45	8
	B	12	9	30	20	19	8
	C	14	18	40	23	10	11
Series II 5% alfalfa added	Ch.	25	45	50	80	51	72
	A	30	33	53	95	85	27
	B	27	30	110	210	146	72
	C	25	27	70	165	313	90
Series III 10% alfalfa added	Ch.	35	60	85	100	400	400
	A	36	15	75	146	311	200
	B	38	14	37	180	420	320
	C	40	12	32	130	473	300

NOTE: *Series I indicates a small increase due to sodium chlorate followed by a similar depression. Series II indicates that rapid nitrification of organic matter will occur in the presence of sodium chlorate, as much of the sodium chlorate remained undecomposed at 10 weeks. In Series III practically all of the sodium chlorate was decomposed at 4 weeks.*

as showing that nitrification will proceed in the presence of chlorate, because the chlorate had not decomposed. The depression of nitrates at four weeks in Series III is probably due to the excessive decomposition of organic matter at that time. At this point practically all of the chlorate had decomposed and nitrification progressed rapidly after that date. Fig. 6 shows the progress of nitrification under Concentration C of each series.

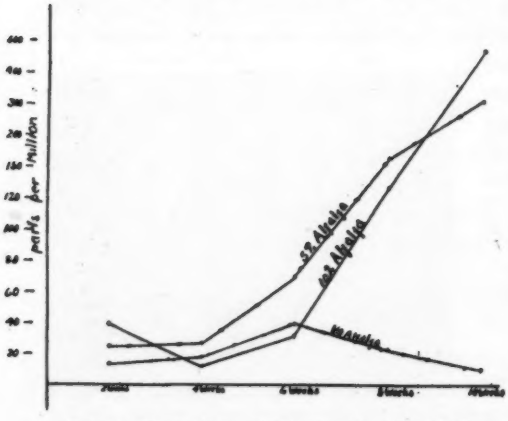

FIG. 6. *Fluctuations of nitrates in soil with Concentration C of sodium chlorate added. This graph shows that nitrification will proceed in the presence of sodium chlorate under greenhouse conditions. With ground alfalfa added the nitrates increased.*

To obtain more accurate information regarding the effect of chlorate on the microflora of the soil, four series were placed in the control chamber at 28° C. The soil used was Winterburn fine sandy loam, and each series consisted of a control and the A, B_1 and C applications of sodium chlorate. One series was removed for analyses every two weeks.

The amount of chlorate still obtainable in the soil at each analysis showed that although a little decomposition took place the greater part remained at the end of the two months (see Table XI).

There was a definite depression of numbers of fungi as shown by the plate count method. Their numbers show a gradual decline following the initial stimulation. This stimulation was probably due, at least in part, to the more ideal conditions of the experiment as compared to the previous condition of the soil. The counts at the end of the first two weeks show a depression in numbers relative to the concentration applied; the higher the concentration of chlorate, the lower the numbers.

TABLE XI

DECOMPOSITION OF SODIUM CHLORATE IN A CONTROLLED LABORATORY EXPERIMENT USING FINE SANDY LOAM. TEMPERATURE, 28° C.

Applied May 5	May 19	June 1	June 16	June 18
None	.005	.006	.004	.002
.026	.0185	.018	.019	.016
.052	.043	.039	.039	.031
.104	.074	.076	.075	.060

NOTE: *Multiplying quantities in the last four columns by ½ will give approximate sodium chlorate left in the soil at each determination.*

The total or bacterial counts were less regular than the counts of fungi but showed a definite decrease for the entire two months as a result of the sodium chlorate applications. Fig. 7 shows the above results graphically.

This experiment suggests that the application of sodium chlorate has a depressing effect on the microflora of the soil when readily decomposable organic matter is not also added to the soil. It is known that various chemical compounds have a decided effect on the behavior of micro-organisms. Such factors as flocculation, pleomorphism and the selective action of the media must be considered. No attempt was made to secure any data beyond the numbers as shown by the plate count. However, it is fully realized that this depression may be only apparent and that the results obtained may be due to factors other than a decrease in actual numbers.

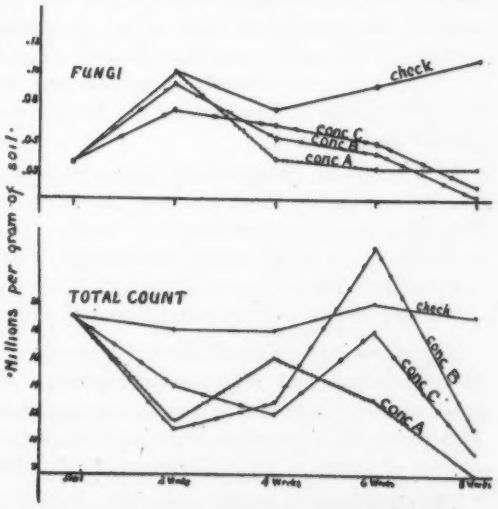

FIG. 7. *Fluctuations in soil micro-organisms due to sodium chlorate treatment. This graph shows that under controlled conditions sodium chlorate depressed the numbers of soil micro-organisms.*

Chemical weed killers have been quite extensively used in the irrigation districts of Alberta. In co-operation with the Field Crops Branch of the Provincial Department of Agriculture, samples were obtained from chlorate-treated plots at Brooks, Alberta.

As these plots had been subjected to both irrigation and seepage and since the chlorate was applied to the standing crop the chlorate analyses were very irregular. However, one or two things seem pertinent. The chlorate follows the water fairly consistently. In the seeped plots it is concentrated near the surface; in the irrigated plots it is concentrated down two or three feet. Plots receiving two irrigations after the chlorate treatment had the chlorate concentrated in the first and second foot. Those receiving three irrigations showed the highest concentrations in the second and third foot.

It is difficult to say if the chlorate carried down will decompose or if it will be carried back to the surface. It does seem reasonable to suggest that under ordinary irrigation practice shallow feeding plants might be grown the year following the application of the chemical, with reasonable success.

Sodium dichromate

As sodium dichromate was showing some promise as a herbicide in greenhouse experiments it was decided to include it in our list.

As a preliminary experiment, eight crocks of Edmonton black soil were treated in duplicate. The concentrations were similar in percentage to the chlorate concentrations used in previous experiments. After being kept moist in the greenhouse for four months these crocks were sown with wheat. At the end of one month no difference in growth whatever was seen in any of the crocks, *i.e.*, there was no residual lethal effect due to chromate. Determinations at the end of the five months showed that the chromate had all decomposed.

As a result of the above preliminary experiment a series of tumblers containing fine sandy loam soil was placed in a controlled chamber at 28° C. The series was increased from four to six. The concentrations used are given in Table I. A wider range was thought desirable because at present there is no definite knowledge as to its lethal concentration. The heaviest application also gives an oxidation equivalent to Concentration B of sodium chlorate.

One series was removed every two weeks. Numbers of fungi and bacteria were obtained and nitrates determined. The amount of Cr_2O_7 decomposition and the effect on a growing crop were also noted every two weeks. The effect on a growing crop was determined by planting and observing growth of wheat in small dishes of the incubated soil.

The experiment with sodium dichromate has given some significant results. Excepting in Concentration A the sodium dichromate had a depressing effect on nitrates and nitrification (see Fig. 8). The heavier applications reduced the nitrates to a very low amount. Concentration A acted as a stimulant and slightly increased the accumulation of nitrates over the check (see Table XII).

TABLE XII

AMOUNTS OF SODIUM DICHROMATE IN FINE SANDY LOAM TUMBLERS

	At start	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Conc. Ch.	.0	.0	.0	.0	.0
Conc. A−	.013	.0	.0	.0	.0
Conc. A	.026	.011	.005	.007	.0
Conc. B	.052	.021	.011	.010	.006
Conc. C	.104	.064	.048	.025	.006
Conc. C+	.146	.117	.86	.030	.012

Amounts of nitrates in p.p.m. in tumblers of fine sandy loam treated with sodium dichromate

Conc. Ch.	9	10	17.5	15.4	15.0
Conc. A−	9	3.5	12.5	20.0	25.0
Conc. A	9	3.0	5.1	3.0	1.5
Conc. B	9	3.1	5.1	2.0	1.0
Conc. C	9	5.0	4.4	1.6	2.0
Conc. C+	9	3.0	4.2	1.6	1.2

NOTE: *These determinations indicate that sodium dichromate decomposes fairly rapidly in common soil, and that nitrification is greatly retarded in its presence.*

The dichromate appeared to decompose under controlled conditions quite rapidly. By the end of the eight-week period only a trace could be recovered from the soil receiving the heaviest concentration, namely, C+ (see Table XII).

Sodium dichromate reduced the number of fungi for the period of eight weeks. Its action, however, on the total count appears to be selective. By comparison with the check plates there was a relative decrease in the main types of colonies with increasing concentration of chromate, but an increase in a typical pin-point colony. In the soil receiving the higher concentrations the latter became very abundant, reaching the extent of over 100,000,000 per gram (see Table XIII).

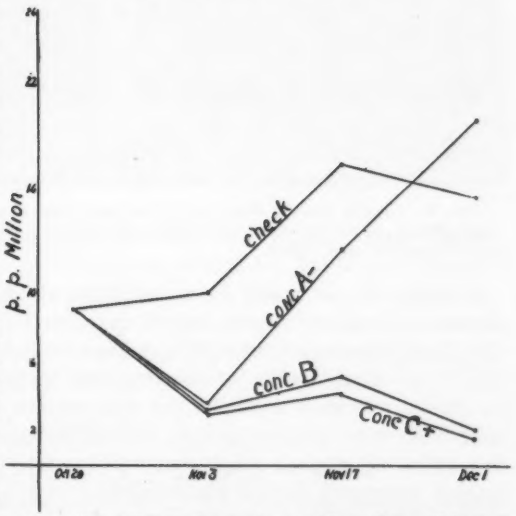

FIG. 8. *Nitrate fluctuations with sodium dichromate treatment. This graph shows the depressing effect of sodium dichromate on nitrification. Determinations were made on fine sandy loam maintained under controlled conditions.*

The growth of wheat every two weeks is shown in Fig. 9. A distinct retardation relative to the sodium dichromate was noted at first. However, later sets showed that this toxicity is not persistent and becomes less apparent. The retarded plants on the soil receiving the higher concentrations did not show the characteristic whitening of chlorate poisoning. Apart from their diminutive growth they appeared quite normal. This retardation persisted after the chromate appeared to have decomposed, which suggested that the effect may be due to factors other than oxidation or direct plant injury.

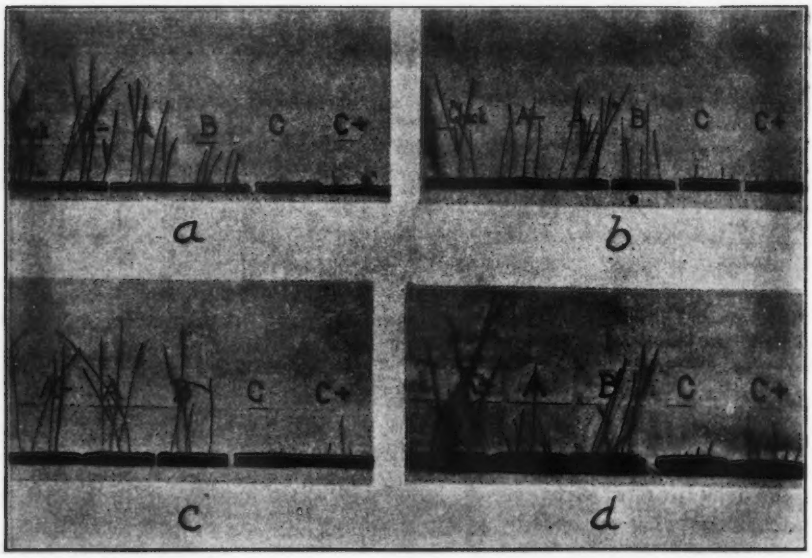

FIG. 9. *Growth of wheat seedlings on fine sandy loam after treatment with sodium dichromate. Seed planted at various times after the chemical was applied. a, two weeks; b, four weeks; c, six weeks; d, eight weeks.*

A series of fine sandy loam tumblers, check and Concentration C, was allowed to incubate in the control chamber for three weeks. At the end of this period they were removed and sown with wheat. One set of Concentration C was treated with potassium nitrate at the rate of 75 p.p.m. of nitrogen as nitrate nitrogen; a similar set was treated with nutrient solution at an equivalent rate with respect to nitrate nitrogen. It was thought that the depression of nitrates might have been partly responsible for the dwarfish growth supported by the chromate-treated soil. Neither the nutrient solution nor the nitrate application appeared to neutralize the effect of sodium dichromate.

One set of the check tumblers of fine sandy loam was treated with chrome alum. The amount of chromium added was equivalent to that in Concentration C of sodium dichromate treatment. The soil receiving the alum supported a normal crop. This indicates that the chromium ion in the cation form is not toxic to wheat plants in the concentration used.

TABLE XIII

FUNGAL NUMBERS IN TUMBLERS OF FINE SANDY LOAM TREATED WITH SODIUM DICHROMATE

	At start	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Conc. Ch.	12	24	30	24	24
Conc. A−	12	15	20	23	20
Conc. A	12	11	24	19	24
Conc. B	12	18	21	27	23
Conc. C	12	16	11	19	13
Conc. C+	12	5	9	13	19
	Times 1,000 = number per gram of soil.				

Total count or bacterial numbers in tumblers of fine sandy loam treated with sodium dichromate

Conc. Ch.	15	13	44	36	35
Conc. A−	15	21	47	20	26
Conc. A	15	12	60	44	33 + 20*
Conc. B	15	7 + 10*	1	111	30 + 78*
Conc. C	15	3	8 + 70*	13 + 75*	8 + 111*
Conc. C+	15	2	5 + 65*	10 + 60*	12 + 101*
	Times 1,000,000 = numbers per gram of soil.				

* *Very small colonies.*

NOTE: *These determinations indicate that the numbers of fungi and bacteria in soil are greatly reduced or affected by the presence of sodium dichromate.*

It was found that 3% of alfalfa added, together with Concentration C of sodium dichromate, to fine sandy loam rapidly neutralized the toxic effect of sodium dichromate. The soil grew a normal crop when wheat was sown three weeks after treatment.

Sodium dichromate added to Edmonton black soil (which is much higher in organic matter content than the Winterburn fine sandy loam used) decomposed very rapidly. A series of tumblers of black loam was treated with Concentration C of sodium dichromate. Immediately after its application 96% could be extracted. In three days only 50% of the chromate could be recovered and in 15 days it had all decomposed.

TABLE XIV

AMOUNTS OF NITRATES IN P.P.M. IN FINE SANDY LOAM AND BLACK LOAM TREATED WITH CONCENTRATION C OF SODIUM DICHROMATE

	Start	8 Days	16 Days	25 Days	34 Days	43 Days
Winterburn F.S.L. Ch.	4	6	15	21	40	25
Winterburn F.S.L. Conc. C	4	Trace	Trace	Trace	4	Trace
Ed. Black Loam Ch.	20	34	80	105	150	100
Ed. Black Loam Conc. C	20	32	62	60	91	85

Sodium dichromate does not appear to depress the nitrates in the black loam to as great an extent as in the fine sandy loam. Table XIV shows the trend of nitrate accumulation over a period of six weeks in an incubation chamber of treated and untreated black loam and fine sandy loam. The nitrate content of the fine sandy loam treated with Concentration C was reduced to a trace for the entire six weeks' period. In the black loam the depression was only 15% for the same treatment at the end of the six weeks' period.

The above experiments have shown that sodium dichromate has an effect on the numbers and kinds of micro-organisms in the soil and that it depresses the amount of nitrates in the soil. This suggested that a measurement of the carbon dioxide evolution might furnish additional information regarding its effect on microbiological activity.

The apparatus set up to measure the carbon dioxide contained three units: one for untreated soil; one for chromate-treated soil; and a sand check. Two hundred grams of soil were used for each unit; one-half was placed in the bottom of a filtering flask and the other half in a connected separatory funnel over the flask. All soils were at optimum moisture when placed in the apparatus and the treated soil had Concentration C of sodium dichromate added. The air from the scrubbers, free from carbon dioxide, was drawn over the first portion of soil in the flask and then passed up through the other half in the separatory funnel. Bead towers containing carbonate-free sodium hydroxide collected the carbon dioxide given off by the soil. An eight-foot water head supplied the suction to draw the air through the apparatus. A flowmeter was inserted between the water head and the sodium hydroxide towers.

Each unit was aspirated 45 min. each day over a period of 45 days, at the rate of 12 litres per hr. Precautions were taken to prevent carbon dioxide contamination and a uniform check was obtained. The sodium hydroxide was titrated against standard hydrochloric acid using phenolphthalein for the first or bicarbonate end-point, and British Drug House indicator for the final end-point.

The results are shown graphically in Fig. 10. The large amount of carbon dioxide given off at the beginning is possibly due to the fact that the soil was air-dry for a considerable length of time before it was used in the experiment. The temperature was not controlled and this might explain some of the small daily fluctuations. There was a distinct retardation for the first two days in the carbon dioxide production from the soil treated with sodium dichromate. This gradually levelled out and from the 12th to 25th day the amount of carbon dioxide produced in the treated soil was greater than in the untreated soil. The curve would suggest something similar to a partial sterilization of the soil. After 12 days, when the amount of carbon dioxide produced by the treated soil became greater than in the untreated, practically all of the sodium dichromate would have been decomposed. These results seem to add more evidence to the fact that sodium dichromate acts quickly

and rather vigorously on the soil micro-organisms, but that the effect is not permanent. The speed with which the soil returns to normal is quite rapid especially if the soil is high in organic matter.

Experiments with sodium chlorate indicated that it was possible to leach the chlorate out of the soil beyond the limit of its toxic concentration. An analogous experiment was conducted using sodium dichromate. Nine leaching tubes, each containing 600 gm. of soil were used. There were three tubes of each of the three types of soil. To two tubes of each soil, Concentration C of sodium dichromate was added. Forty-eight hours were allowed, to bring the soil and solution to equilibrium. It was intended to leach six inches of water through each tube, but as there was still a considerable amount of chromate in the leachings with that amount, a total of ten inches was collected. There was only a trace of chromate in the fraction caught from a further ten- to twelve-inch leaching. The results are shown in Table XV.

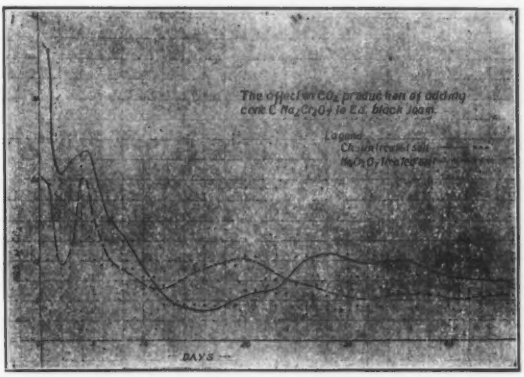

FIG. 10. *This graph shows the effect of sodium dichromate on carbon dioxide production. The determination was made on Edmonton black loam.*

TABLE XV

SODIUM DICFROMATE RECOVERED FROM SOILS BY LEACHING 48 HR. AFTER IT HAD BEEN APPLIED

Soil	Gm. of $Na_2Cr_2O_7$ added	Gm. of $Na_2Cr_2O_7$ retrieved	Av. gm. retrieved
Black 1	0.624	0.1001	
Black 2	0.624	0.1016	0.1008
Wooded 1	0.624	0.2146	
Wooded 2	0.624	0.2235	0.2190
F.S.L. 1	0.624	0.3608	
F.S.L. 2	0.624	0.3229	0.3419

The ten inches of water leached through contained 16.1% of the chromate that was added to the black soil; 35.1% of that added to the wooded grey soil; and 54.8% of that added to the fine sandy loam. This further suggests that the chromate is rapidly decomposed in the soil. If chromate is added to a soil and immediately extracted, from 92 to 96% is retrieved.

The soil from the leaching tubes was removed and planted with wheat. A normal crop grew on all soils. Or in other words no toxic effects appear to have remained in the soil.

A series of wheat plots in duplicate was sprayed with four concentrations of sodium dichromate on July 1. The concentrations used were one-half of those shown under Concentrations A, B, and C in Table I. Considerable damage resulted from the treatment. It killed the leaves of the wheat plant and blighted many of the heads. Concentration C reduced the yield of wheat to 4 bu. per acre as compared with 29 bu. on the check plot.

Water Culture Experiments

Experiments were conducted to determine the concentrations of certain chemical herbicides toxic to wheat plants in water or nutrient solution cultures. The effects of chemical herbicides upon plant roots may be modified by the presence of soil, and it was considered that the relative toxicity of different chemicals might be determined more definitely in a nutrient solution than in soils. There are fewer complicating factors in a nutrient solution, diffusion is rapid, and the solution can be standardized.

A standard plant culture solution, first recommended by Hoagland, was used in these experiments.

It was considered desirable first to test important perennial weed killers, since these are believed to have an important effect upon the roots of plants within the soil. The chemicals first tested were sodium chlorate and sodium dichromate.

TABLE XVI

EXPERIMENTS TO DETERMINE RELATIVE TOXICITY OF DIFFERENT CHEMICALS IN CONTACT WITH SPROUTING SEEDS

No. of gm. per litre	Solution	Wheat seeds set to sprout	Number germinated	Av. length of sprouts, in.	Variation in length of sprouts, in.
Sodium chlorate				*Notes 4 days later*	
0.0	Dist. water	25	24	1¾	⅛ – 2¼
0.0	Nutr. sol.	25	24	2	½ – 2¾
1.0	Dist. water	25	25	¾	⅛ – 1⅛
1.0	Nutr. sol.	25	23	1¼	⅛ – 1¾
3.0	Dist. water	25	25	⅝	⅛ – 1
3.0	Nutr. sol.	25	23	⅝	⅛ – 1⅛
Sod. dichromate				*Notes 5 days later*	
0.0	Dist. water	25	24	1½	½ – 2¼
0.0	Nutr. sol.	25	24	2	½ – 2¾
1.0	Dist. water	25	24	¼	1/16 – ½
1.0	Nutr. sol.	25	20	¼	1/16 – ½
3.0	Dist. water	25	11	⅛	1/16 – ¼
3.0	Nutr. sol.	25	7	⅛	1/16 – ¼

NOTE: *Wheat seeds were sprouted between blotting papers in Petri dishes. After moistening with the original solution, moisture was maintained by adding distilled water.*

The experiments indicate that sodium dichromate is much more toxic to germinating wheat than sodium chlorate, in equal concentration. A concentration of 1 gm. sodium dichromate per litre appears to be more toxic than a concentration of 3 gm. sodium chlorate per litre.

TABLE XVII

EXPERIMENTS TO DETERMINE RELATIVE TOXICITY OF DIFFERENT CHEMICALS IN NUTRIENT SOLUTION CULTURES

Sodium chlorate, gm. per litre	Age of plants on adding chemicals, days	Notes 14 days later	Sodium dichromate, gm. per litre	Age of plants on adding chemicals, days	Notes 13 days later	Sodium chlorate, gm. per litre	Age of plants on adding chemicals, days	Notes 10 days later
0.0	18	Checks healthy	0.0	15	Checks healthy	0.0	32	Checks healthy
0.1	18	Like checks	0.1	15	Much wilted	0.1	32	Like checks
			0.3	15	Practically dead	0.3	32	Slightly wilted
0.5	18	Partly wilted	0.5	15	Practically dead	0.5	32	Much wilted
1.0	18	Much wilted	1.0	15	Practically dead	1.0	32	Practically dead
3.0	18	Much wilted						

NOTE: *Duplicate litre (or quart) jars were used for each treatment, and 5 (usually) wheat seedling plants were set in each jar. Chemicals were added after plants had made a fair growth.*

The experiments indicate that, when placed in contact with the roots, sodium dichromate is toxic to the wheat plants in much lower concentration than sodium chlorate; 0.1 gm. sodium dichromate per litre appears to be quite as toxic as 0.5 gm. sodium chlorate.

The relative toxicity of different chemicals in contact with sprouting seeds was determined by sprouting wheat seeds between blotting papers in Petri dishes. After moistening with the original solution, moisture was maintained by adding distilled water. Germination and growth of sprouts was observed four or five days after the seeds were moistened.

The experiment (see Table XVI) indicated that sodium dichromate is much more toxic to germinating wheat than sodium chlorate, in equal concentration. A concentration of one gram of sodium dichromate per litre appeared to be more toxic than a concentration of three grams of sodium chlorate per litre.

The relative toxicity of different chemicals in contact with plant roots was determined by adding chemicals to nutrient solutions in which plants were growing. Duplicate litre, or quart, jars of nutrient solution were used for each treatment and five (usually) wheat seedling plants were set in each jar. Chemical herbicides were added after plants had made a fair growth, and the effects, if any, on the appearance of the plants, were noted a few days later.

The experiment (see Table XVII) indicated that, when placed in contact with plant roots, sodium dichromate is toxic to the wheat plants in much lower concentration than sodium chlorate. For example, 0.1 gm. of the dichromate per litre appeared to be quite as toxic as 0.5 gm. of the chlorate.

Experiment with Barium Chlorate

A preliminary greenhouse experiment with barium chlorate was outlined. Duplicate crocks of fine sandy loam were treated with barium chlorate using the concentrations shown in Table I. The amounts used were equivalent in oxidizing values to the concentrations of sodium chlorate used throughout this work.

The effects on wheat sown six months after the application of the barium chlorate showed that it was at least as toxic as sodium chlorate.

Summary

1. Soil experiments with several chemical herbicides were conducted in the field, in the greenhouse and in a controlled chamber. Generally three typical Alberta soils were used for pot culture work.

2. The special methods adopted for the determination of small amounts of chlorates in soils and for the determination of nitrates in the presence of chlorates are outlined, and all methods used are stated in the body of the paper.

3. Sulphuric acid in quantities used for control of annual weeds appeared to have no residual lethal effect on the Alberta soils studied.

4. Copper sulphate in quantities used for the control of annual weeds appeared to have no lethal after-effect on these soils. Nitrification was but slightly affected following its application. It did increase the percentage of grain to straw when applied to the growing crop, and an appreciable decrease in yield due to the copper sulphate might have been shown if the check plots had not lodged.

5. Much of the sodium chlorate applied will remain undecomposed in moist soils under greenhouse conditions for at least 18 months.

6. Sodium chlorate retained its toxicity in the Edmonton field for at least one year.

7. Sodium chlorate will move with the soil water and in a period of average or high rainfall will concentrate in the subsoil, *i.e.*, leaching plays an important part in its distribution and toxicity.

8. With the rainfall of Edmonton, 1931 (approximately 17 in. from May to September inclusive) the surface foot was practically freed of the toxic effect of sodium chlorate. This suggests that shallow-rooted crops might sometimes be grown more successfully than deep-rooted crops following its application.

9. Sodium chlorate, in the quantities used in these experiments, did not prevent, or greatly affect nitrification. Nitrification proceeded rapidly in the presence of chlorate when nitrogenous organic matter was added to the soil.

10. In controlled laboratory experiments sodium chlorate had some depressing effect on the numbers of soil micro-organisms.

11. Twenty-five tons of manure, one ton sulphur or one ton sulphuric acid per acre in pot cultures did not aid decomposition of sodium chlorate in a marked degree.

12. Approximately 10% organic matter in the form of alfalfa in pot experiments promoted rapid decomposition of sodium chlorate. This suggests that under favorable conditions, the toxic effect of sodium chlorate may be removed from the surface soil by incorporating a large application of readily decomposable organic matter with the surface soil.

13. Sodium chlorate does not appear to leave any toxic oxidation products of its decomposition.

14. Sodium dichromate in comparison with sodium chlorate appears to decompose in the soil very rapidly. Practically all of it decomposed in eight weeks in Winterburn fine sandy loam and in two weeks in Edmonton black loam.

15. In controlled laboratory experiments sodium dichromate had a depressing effect on the numbers of soil micro-organisms. It also had a decidedly depressing effect on soil nitrification in pot cultures.

16. The addition of 75 p.p.m. of nitrate nitrogen to fine sandy loam three weeks after the application of sodium dichromate failed to neutralize the toxic effect of the chromate.

17. Fine sandy loam containing 3% of ground alfalfa supported a normal crop three weeks after a heavy application (Concentration C) of sodium dichromate.

18. Sodium dichromate reduced the amount of carbon dioxide produced from Edmonton black loam. The reduction was quite marked for the first two days.

19. Leaching ten inches of water through the soil, 48 hr. after the application of sodium dichromate, led to the recovery of only a small percentage of the chromate added. Wheat sown immediately after leaching, however, grew normally.

20. Water or nutrient solution culture experiments indicate that when placed in contact with germinating wheat seeds, and in contact with growing wheat plant roots, sodium dichromate is much more toxic to wheat than sodium chlorate in equal concentration.

21. A preliminary experiment indicates that the toxicity of barium chlorate is similar to that of sodium chlorate.

(NOTE:—In testing the residual effect on crop growth in all laboratory experiments, wheat was the only plant used.)

Acknowledgments

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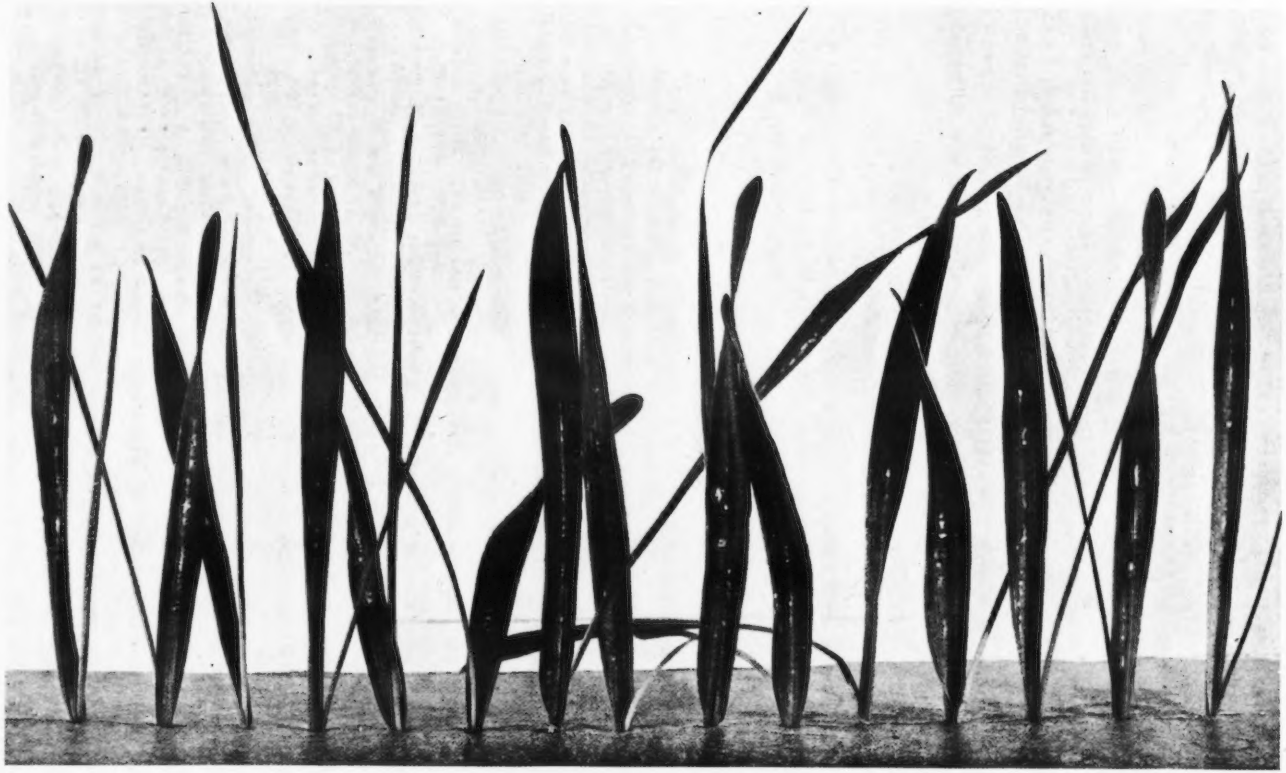

FIG. 1. *Seedling barley plants showing the effect of nematode infestation—natural size*

THE NEMATODE DISEASE OF NARCISSI AND CROP SEQUENCE[1]

By R. J. Hastings[2], J. E. Bosher[2] and W. Newton[3]

Abstract

The characteristic symptoms of nematode infection appeared in barley, oat and wheat seedlings as the sequence of planting the seed in soil infested with the nematode species, *Tylenchus dipsaci*, Kuhn, from narcissi bulbs. The severity of the infection was greater in barley and oats than in wheat.

In an investigation aimed at the establishment of a suitable crop sequence or rotation for the prevention and control of the nematode disease of narcissi, sterilized soil in six-inch pots was inoculated with the ground pulp of narcissus bulbs that was heavily infested with living nematodes of the bulb species *Tylenchus dipsaci* (Kuhn), and the pots were planted with barley, wheat and oats. Four weeks later, the characteristic symptoms of nematode infection, namely, the raised white spots, were apparent on the foliage of all three classes of seedlings. These raised white areas were more abundant along the midribs of the leaves than elsewhere. Although some distortion of the leaves occurred with all three classes of seedling, the distortion was conspicuous in the case of oats and barley. As judged by the foliage distortion and number of lesions, oats and barley are more susceptible to infection than wheat seedlings. No lesions were examined that did not contain living nemas and eggs. The appearance of nematode-infested barley seedlings is shown in Fig. 1.

The writers' observation of the severity of nematode infestation of barley seedlings does not support the conclusion of Massee (1, p. 548) that barley is a safe crop in a rotation. Massee pointed out that clover and oats are unsuitable rotation crops owing to the fact that the bulb nematode, *T. dipsaci* (syn. *T. devastatrix*) is responsible for clover sickness and the segging of oats.

Although barley, oats and wheat are included among the list of plants attacked by *Tylenchus dipsaci*, compiled by Steiner and Buhrer (2), no report of actual observation of barley and wheat infection by this nematode has has been published by American or Canadian authorities. The writers' inoculation experiments show that under greenhouse conditions favoring rapid seedling growth, the characteristic raised yellow lesions appear less frequently than under slow growth conditions. This phenomenon may account for the lack of field observations upon wheat and barley infestations.

Acknowledgment

The authors wish to thank Dr. G. Steiner, United States Department of Agriculture, for confirming the identity of the nematode species.

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REVIEWS AND NOTES

THE NATURE OF THE MECHANISM OF POLYMERIZATION[1]

By Harold Hibbert[2] and Stanley Z. Perry[3]

During recent years considerable evidence has been obtained by Staudinger, Carothers, Haworth, Meyer and Mark, and others, indicating that highly polymerized products, such as cellulose, starch, rubber, etc., represent long-chain normal valence compounds formed from a simple building unit by addition of one molecule to another, although no conclusive proof of this "stepwise" formation has been provided.

In view of the close relation existing between polymerized ethylene oxide and cellulose, work was begun some eight years ago on the mechanism of polymerization of the former, and experimental evidence has now been obtained in support of the theory that this takes place in the following manner:—

A molecule of ethylene oxide is first activated by the catalyst (aqueous alkali). Ring fission then occurs followed by addition of water to give ethylene glycol. The latter, in turn, adds on to another molecule of the open chain form of ethylene oxide, giving diethylene glycol, and so on. The mechanism involved is the addition of HX to the open chain form of ethylene oxide, X representing $-(OCH_2CH_2)_y OH$, where y has the values of 0, 1, 2, 3, etc. The writers have isolated in this way the mono-, di-, tri-, tetra-, penta-hexa-, hepta-, octa- and nona-ethylene glycols from such polymerization products, in addition to mixtures of the higher solid crystalline polyethylene glycols. Water is apparently necessary for this reaction, no change taking place with solid alkali alone. Substitution of a higher polyethylene glycol for the water yields a series of polyethylene glycols higher than the one employed.

Preliminary experimentation indicates that with methyl alcohol the terminal groups are (OCH_3) and (OH), while with amines $(R.NH_2)$ they are probably $R.NH-$ and (OH).

The evidence obtained is regarded as providing strong support for the view that in this, and a wide variety of other cases, the mechanism of polymerization consists, first, in the presence, or primary formation, of an unstable ring—the latter formed in many cases through the medium of the catalyst; second, in the transformation of this ring into an open chain form with activated terminal groupings followed by addition of the two addenda H and X, thus giving rise to chain formation.

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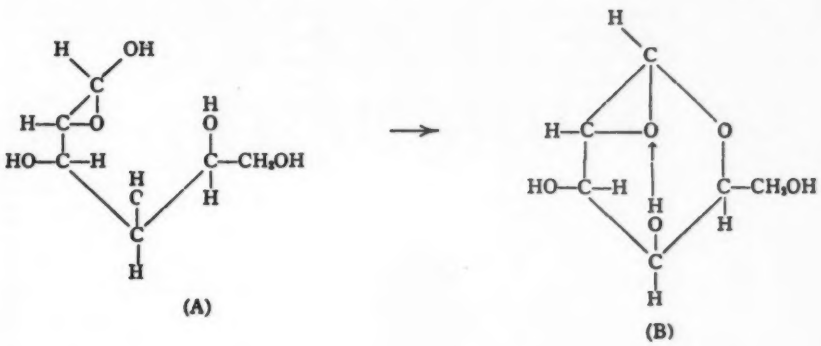
THE PLANT SYNTHESIS OF CARBOHYDRATES AND POLYSACCHARIDES[1]

By Harold Hibbert[2]

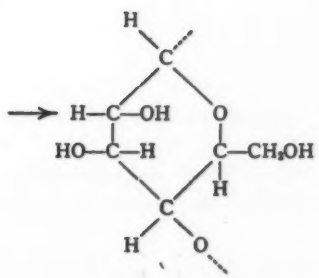
In the preceding communication (1) attention is drawn to the experimental proof obtained recently regarding the mechanism of ethylene oxide polymerization.

The further suggestion is now advanced that this theory also provides a working hypothesis for the plant synthesis of the more complex sugars and polysaccharides.

It has been pointed out on several occasions in recent years, in addresses to the Cellulose Division of the American Chemical Society and elsewhere, that the synthesis of cellulose and starch in the plant probably takes place through the ethylene oxide equilibrium form of glucose and fructose (A) which, by loss of a molecule of water, may be assumed capable of yielding the glucose anhydride (B).



(A) (B)



(C)

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Disaccharide formation can thus be regarded as taking place by the simple addition of a second molecule of a hexose (HX) to the free valence form of the ethylene oxide ring in (B), the disaccharide in turn then adding on a second molecule of (B) to give a trisaccharide, and the process representing an *intermolecular* chain synthesis.

On the other hand the synthesis of the more complex polysaccharide chains, such as cellulose, starch, glycogen, inulin, etc., may be visualized as being brought about by an *intramolecular* glycidol chain polymerization, as postulated in the conversion of (B) to (C). Such changes admit of an equally satisfactory explanation if considered as proceeding directly through the medium of the intermediate form (A) with simultaneous removal of water.

The theory thus represents an application of the chain mechanism for the thermal polymerization of glycidol first postulated by Nef (7, p. 232) and supported later by the work of Levene and Walti (2-6).

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